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VOLUME 15 PART 1

Journal of the Rubber Research Institute of Malaya

Foreword Our Journal was founded for the publication of records of the scientific work of the Institute undertaken for the Malayan rubber producing industry, and commenced publication in 1929 under the title of the *Quarterly Journal* of the R.R.I. This issue appears in a new format which we hope will encourage and assist us towards improved presentation of the detailed results of our research. To maintain continuity, papers and progress reports will continue to bear serial Communication numbers.

With a Journal which serves to present the work of those engaged in many branches of science, editorial regulation must be flexible; however we shall aim at greater uniformity in certain matters. Beneath the title of each paper will appear a brief abstract — while a summary, if deemed necessary, will be given at the end of the paper. The purpose of the abstract is to indicate the contents and scope of the paper without summarising or giving results, so that the reader may decide whether or not to peruse the paper at length.

In addition to reports of experimental work and research carried out at the Institute, we intend to include the occasional paper devoted to a review of work done elsewhere, in order to provide a fuller background to some of our own more specialised studies.

Although it will be our aim to prepare each paper in a form which will be as widely acceptable as possible, it will be appreciated that the readership will be primarily scientific and will include those who are most closely concerned with the application of the results of scientific research to practice in the natural rubber producing industry.

In this connection we have considered the present distribution of our Journal and have decided to maintain the custom of sending one copy gratis to the management of each rubber estate in Malaya on our list.

An innovation which will affect future contents is the recent introduction of R.R.I. Research Archives which are kept in the Library of the Institute, to accept the formal deposit of experimental documents. Detailed tables of experimental data can be so deposited and copies will be provided whenever the need arises. By this provision papers appearing in the Journal should be more succinct.

We shall continue to publish at irregular intervals as new work comes forward and each volume will be completed when a suitable number of pages is reached.

The price of each issue will be fixed according to its size; there will therefore be no annual rate of subscription but a statement of account will be sent to each subscriber after the end of the year.

C. E. T. Mann

Director

Rubber Research Institute of Malaya

Cover Plants in Rubber Cultivation

G. A. WATSON

A review is given of the literature concerning the probable effects of cover plants on tree growth and soil conditions in relation to rubber cultivation. Particular attention is paid to the cultivation of leguminous creepers and to the comparative effects of leguminous and non-leguminous cover plants.

THE USE OF PERMANENT COVER PLANTS interplanted with the main crop is common practice in tropical plantations, their presence serving to protect the crop and soil from the more extreme climatic conditions. In tea and coffee plantations shade trees are provided to protect the plants from excessive heat, and in oil palm, rubber, coffee, tea, and sisal plantations a ground cover of creeping plants or upright shrubs is maintained to protect the soil from insolation and erosion effects. With some of the richer tropical soils a catch crop can be used as the ground cover; for instance, gambier, tapioca, bananas, hemp, and pineapples have been planted at times in rubber plantations (ALLEN 1955), but this is now exceptional and the practice is mainly restricted to smallholdings.

Much investigation into the cultivation of cover plants in rubber plantations has been carried out in the former Dutch East Indies territories of Java and Sumatra, and for a review of the agronomical aspects of this work the reader is referred to M. J. Dijkman's book *Hevea**. The present text refers more particularly to such cultivation under Malayan conditions.

The policy of growing cover plants in conjunction with rubber has not always been in favour in Malaya. The early planters found that young rubber trees grew best in the absence of competition from other plants and so a clean weeding system developed in which the ground surface in rubber plantations was maintained completely bare of all weeds. Soil erosion became a serious problem and was countered by the use of elaborate silt pit systems designed to check the wholesale loss of top soil. This method had its limitations however and, partly due to the economic depression of the late 1920s when the maintenance of clean weeded areas became too expensive, the value of growing a cover plant together with rubber became recognised.

Two main practices have since developed, one making use of indigenous plants as the cover, the other involving the maintenance of specially sown leguminous creepers or shrubs for at least the first few years in the life of a plantation.

The first practice took its most extreme form in the 'forestry' system of planting as advocated by a practical forester F. Birkemose. This system (R.R.I.M. 1932) was based on the belief that a system of cultivation which allows the natural environment of the rubber tree to develop should be of maximum advantage to its growth. Accordingly as the rubber tree is a plant of the tropical rain forest, it was thought that the young rubber seedlings which spring up in plantations should be allowed to develop and after selective thinning to eliminate low yielders they should be used to replace the older trees as those passed out of tapping. In some cases the young seedlings were to be budded with selected material so as to raise the general standard of the plantation. Other plants growing in association with the rubber were either selectively eliminated on the basis of their supposed effects on soil acidity, on their rooting characteristics or on their degree of woodiness, or alternatively slashed to provide a general ground cover.

* See bibliography, page 17.

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This system attracted some attention (VAN HEUSDEN 1932, ROELOFFS, 1936, EATON, 1935) but because of the great difficulty experienced in bringing self sown seedlings to tappable size it was not adopted in practice. However, the value of Birkemose's system, in allowing the development of a cover of indigenous shade-tolerant plant species in rubber plantations, was recognised, and the term forestry is still applied to the system which permits the development of natural covers as discussed in W. B. Haines' revised edition of *The Uses and Control of Natural Undergrowth on Rubber Estates* between the rubber tree rows. In some cases such growth consists mainly of creeping plants and small shrubs, but at times quite heavy bush growth develops; both are controlled by periodical slashing and selective thinning.

The second main practice is the use of creeping legumes as cover plants. Such cover plants are expensive to establish and to maintain and much controversy centres on the advantages to be gained by undertaking their cultivation in preference to retaining and encouraging non-leguminous indigenous cover plants.

It must not be assumed from the foregoing that a simple choice exists between establishing on the one hand a cover of indigenous creepers and shrubs, and on the other hand a cover of specially sown leguminous creepers or shrubs. There are many factors that can affect the issue; regeneration of indigenous covers will be more vigorous in new clearings from jungle and in a 'no burn' clearing than in a 'burn' clearing, and in replanted areas will be more vigorous and composed of more varied species when the clearing is near a jungle site than where it is surrounded by rubber plantations or other cultivated land. On the economic side the selective weeding carried out in a cover of indigenous plants may initially be more expensive than that carried out in a sown cover of leguminous creepers, but as these creepers tend to be succeeded by troublesome grasses as the shade of the maturing rubber trees develops, eventual weeding costs may be more for the leguminous cover plant. The succession of plants in both types of covers may be markedly affected by soil type, and the soil nutrient and moisture status, and whereas over the years on one site a cover of indigenous plants may show advantages over a cover of leguminous plants, the reverse may be true on another site. The choice of the cover plant system to be adopted may be influenced largely by such practical points as are outlined above, but in order to understand some of the more fundamental factors affecting the performance of the two broad classes of cover plants the relevant practical and experimental observations on the subject are reviewed.

The respective merits of the different cover plant systems are of main concern during the initial years in the life of a plantation, perhaps up to the time of commencement of tapping. At this stage the increased shade under the trees will increasingly restrict all but the most shade tolerant of plants and soil protection becomes mainly dependent upon the litter of fallen rubber leaves. Exceptions occur, depending on climate and soil conditions, and constitute special cases which will be discussed.

As an introduction to the use of cover plants brief consideration will be given to the two types of planting; planting in a recently cleared jungle area (new planting) and planting in a former rubber growing area (replanting).

NEW PLANTING

The sequence of soil degradation likely to follow the clearing of virgin jungle in tropical countries has often been stated and only a recapitulation need be given here. In Malaya, a large proportion of soils are highly leached and possess low nutrient and organic matter reserves. Under jungle the closed canopy maintains cool, moist, soil conditions and with the constant circulation of mineral nutrients and organic matter

effected by the abundant and varied plant growth a stable, reasonably fertile condition exists. However, when the jungle is cleared the cycle is broken and insolation and leaching increase to such an extent that reserves of fertility may be quickly exhausted. The rate of deterioration will vary widely depending on the soil type and topography and it is essential that some protection be afforded to the soil as soon as possible after clearing. In most jungle clearings all valuable timber is extracted and the remaining logs are roughly stacked in heaps for burning or are piled between the rubber tree planting rows and are allowed to rot down. The remains of these logs and stumps provide some protection to the soil immediately beneath them and seedlings of indigenous creepers and upright growths quickly appear. In addition planters often sow leguminous cover plants immediately after clearing, particularly where a burn has been carried out which may check the development of indigenous plants, and the two types of cover plants quickly produce a vigorous and luxuriant ground cover which affords ample protection to the soil. The luxuriant growth of the cover stems from the reserves of fertility left in the soil by the original jungle flora.

REPLANTING

Old rubber plantations, originally planted in cleared jungle, will have had little or no fertiliser applications for many years and the reserves of fertility will be near exhaustion except on the very best soils. If the old rubber wood is not removed but burnt or allowed to rot in situ certain amounts of nutrient and organic matter will be returned to the soil (Akhurst 1939, Dyck 1939) and its immediate fertility will be slightly enhanced thereby. However, the rapid establishment of cover plants on such impoverished soils is imperative so that protection can be afforded against erosion and the organic matter status of the soil can be built up again. Few seeds are found in the surface soil in such areas, especially after periods of clean weeding under which system many of the old rubber areas were originally maintained, but there may be sufficient to regenerate and form a useful cover after the shading effect of the old trees is removed; in general, however, fresh sowings of legume seeds need to be carried out. On poor soils difficulty is sometimes encountered in the establishment of the cover plant and it may be some six months or more before a satisfactory cover is obtained.

ESTABLISHMENT AND MAINTENANCE OF COVER PLANTS

Indigenous covers are generally of spontaneous development but when required they can be introduced by seeding or by the use of cuttings The only maintenance they receive under normal estate practice is that of regular slashing and selective weeding, carried out in order to encourage growth of the softer tissued plants and to keep out unwanted grasses and other plants. Leguminous cover plants on the other hand generally require to be specially sown, although sometimes a good leguminous cover can regenerate from dormant seed in the ground. The seed is preferably pretreated (R.R.I.M., 1954) and inoculated with nodule bacteria and is often sown together with a phosphate dressing. Once established the creeping leguminous cover plants will usually smother other plants and during their period of maximum vigour, the first three years, can generally be maintained by broadcast applications of rock phosphate and some selective weeding.

The cultivation of cover plants in association with the rubber trees involves a number of problems In the first year after planting the young rubber trees are generally grown along clean weeded strips some four to six feet wide. In between the tree rows vigorous cover plants develop which may offer serious competition for the reserve of soil moisture, and on freely draining sandy soils drought conditions may result in the planting row. A depressive effect of leguminous cover plants on

the growth of rubber trees at this stage has been reported (HAINES 1932, 1933). It cannot easily be countered by slashing or spraying to restrict the growth of the cover plants for such operations at this stage might check the cover and permit invasion by undesirable species. In general, however, the maintenance of clean weeded areas around the rubber plants, the encouragement of vigorous growth by the regular application of fertilisers, and the use of mulching practices, will ensure satisfactory growth of the rubber. Where these measures are omitted the competition offered by the cover plants may become serious.

After the first year of growth the rubber tree roots spread into the inter-row areas occupied by the cover plants. By this time creeping cover plants, if well maintained, should show a continuous mat of growth, perhaps standing two to three feet high and completely covering all logs and other decaying debris in the area. Under this mass of vegetation a layer of decomposing leaf and stem litter will have developed and cool, moist top soil conditions will exist. Rubber roots ramify easily through the upper soil and organic matter layers and the beneficial conditions contrast sharply with inter-row areas where vigorous grasses and hard woody shrubs have been allowed to develop.

As the rubber trees grow and the leaf canopies develop, the increasing shade depresses growth of the cover plants and, if a leguminous cover plant has been established, increasing difficulty is found in maintaining its purity. Indigenous plants that are more shade tolerant than the legumes are favoured by these conditions and grasses may become established. The maintenance of purity of a stand of leguminous cover plants by selective weeding becomes more expensive and in the great majority of cases the cover plants die out and a sparse stand of a few shrub species and a thin covering of grasses remain. Where the rubber develops a very heavy canopy even the few remaining cover plants may be shaded out leaving the bare soil protected only by decaying rubber leaf litter. These conditions are not fully satisfactory for during the subsequent life of the plantation, which may be thirty years or more, it is possible for marked soil deterioration to occur. On some of the freely draining sandy soils, which have supported reasonable growth in one generation of rubber trees, difficulty can be experienced in establishing replantings. It appears that in addition to physical effects such as surface soil wash occurring on hilly sites, nutrients tend to be leached out of the upper soil layers in the mature rubber plantation on these soils. There is too little evidence to say in what degree the deterioration is due to the absence of covers or to other factors, and in what way the condition can be remedied, but the subject seems worthy of further investigation.

The preference for leguminous cover plants shown in most estate policies during the early years of the life of a plantation is guided by recommendations based on general field experience and by inferences drawn from experimental work on leguminous plants mainly done in temperate climates and only to a lesser extent in the tropics. Until conclusive results are obtained from experiments carried out in Malaya the advantages of leguminous over non-leguminous cover plants will continue to be the subject of controversy. Field observations on estates are often of little value for rarely can direct comparisons of the two systems be found on adjacent areas. Planters have conflicting views on the subject; those who are not impressed by the advantages claimed for legumes suggest that rather than incur the expense of establishing and maintaining leguminous cover plants, indigenous creepers and shrubs should be allowed to develop naturally, and that selective elimination of certain recognised undesirable species should be carried out. It is argued that if a plant is naturally fitted to a particular ecological association it will maintain as good a growth as an imported legume plant and be much less expensive to establish and maintain.

This is reasonable and the hypothesis receives considerable support particularly in areas where leguminous cover plants can be established only with difficulty. Planters who favour leguminous cover plants argue that few plants can produce such a satisfactory cover so quickly and that in addition the legumes may add nitrogen to the soil. As Malayan soils are often low in nitrogen the latter is an important point.

A cover of creeping legumes may be several times more expensive to establish and maintain than a cover of mixed indigenous shrubs and definite advantages must be offered by the leguminous cover plants before this difference can be ignored. In the following sections the comparative effects of the two types of cover plants upon the soil and upon the growth of the tree are discussed in an attempt to assess the position.

EFFECT OF COVER PLANTS ON THE ORGANIC MATTER CONTENT AND STRUCTURE OF SOILS

Many Malayan soils, particularly those that have carried one generation of rubber trees and are due for replanting, have low reserves of plant nutrients and organic matter and are of poor structure. As a result of their low permeability to rainfall such soils are susceptible to drought and erosion, and cover plants are used in an effort to re-establish satisfactory soil conditions.

Cover plants, by protecting the soil surface against compaction by heavy rain and by virtue of the binding affects of their roots on soil particles, safeguard and improve soil structure. The organic matter that they add to the soil as dead leaf, stem, and root material, also plays a very large part in the improvement of soil conditions by a summation of chemical, physical, and biological effects (Bremner 1956, Cornfield 1955, Duley 1952).

Most plants could be expected to improve soil structure but wide variations in their individual effect are found, as dicussed by W. B. Haines in *The Uses and Control of Natural Undergrowth on Rubber Estates*. With a few exceptions most grasses do not greatly improve the soil under rubber planting conditions. Their mat of surface roots competes strongly for available moisture and the hard dry conditions observed under grass do not encourage free surface rooting by the rubber tree (van Heusden 1934). Grasses can check soil erosion (Smith & Abruna 1955) but there is little else to recommend them in rubber plantations (van der Veen 1935).

Creeping cover plants on the other hand, leguminous or otherwise, exert a marked beneficial effect upon soil structure. No detailed figures are available but observation seems to show that such cover plants return much more organic matter to the soil as dead leaf and stem material than do the grasses. In addition the dead material has a higher nutrient concentration than does that of the grasses. The dense growth of a vigorous, creeping cover plant ensures cool and moist conditions at the soil surface, and a loose, permeable, top soil layer, with a high organic matter content, develops. Soil erosion under such a cover is low.

Under forestry methods of cover plant control, upright woody plants often develop and their use is sometimes recommended on compacted soils where their strong rooting characteristics help to break up and aerate the soil. Such cover plants are controlled by periodical lopping and considerable amounts of material, perhaps up to 20 tons per acre, can be returned to the soil in this way. The litter of fallen stems, leaves, and loppings, protects the soil against heavy rain but erosion control is not likely to be so good as under a creeping cover plant (Haines 1932).

The above comments are based mainly on practical observations as little experimental evidence is available on the effect of cover plants on soil structure under conditions such as exist in Malaya.

EFFECT OF COVER PLANTS ON SOIL NUTRIENT STATUS

In the first year of growth in a rubber plantation, clean weeded or mulched areas are maintained in the immediate vicinity of the tree and there is little competition beween the nutritional demands of the tree and those of the cover plant. As the tree grows, however, its root system spreads into the inter-row area under the cover plant and it seems likely that competition for the available nutrient supply will develop, particularly as the greater proportion of both root systems exists in the top twelve inches of soil. Such competition need not necessarily be harmful over a long term period, as the nutrients taken up by the cover plant, and rendered unavailable to the rubber tree in the first instance are eventually returned to the soil in dead plant material and will again become available for uptake by either the rubber tree roots or cover plant roots. Such action will minimise the leaching of nutrients and, by conversion of mineral nutrients in the soil into components of decaying plant material, their eventual availability to the rubber tree may be actually increased (DE GEUS 1941). This may be particularly so in the case of phosphate (FULLER et alii 1956) which can be very rapidly fixed by certain Malayan soils. The suggestion receives particular support from the fact that rubber roots spread freely through the litter layer underneath a cover plant; decaying leaves, stems, and woody material are all penetrated by the roots and the direct uptake of nutrients from this litter seems possible. This effect may have major implications in fertiliser practice. The levels of fertiliser at present applied to immature rubber plantations are based on experiments using current estate methods of cultivation, that is, the system of applying fertilisers in the main to the clean weeded planting rows, either broadcast or applied in pockets. Few experiments have been carried out applying fertilisers broadcast on the cover plants with the intention of encouraging vigorous growth of these plants. If such a system were used the increased amounts of dead plant material returned to the soil surface might have a marked effect on rubber tree growth. It may be reasoned that frequent application of fertilisers to the clean weeded planting rows is a more direct and efficient method of supplying nutrients to the rubber tree, but as the use of cover plants is essential for protection of the soil there may be advantages in deliberately applying the fertilisers to the cover plants.

A new approach to the problems of plant competition for soil nutrients is suggested by recent work on the cation exchange capacity of plant roots (MEHLICH & DRAKE 1955). Theory suggests that plant roots have differing specific absorptive capacities for mineral nutrients in the soil and an electrometric titration method can be used to determine these capacities. As a result of these differences, intensive competition for soil nutrients can exist between the roots of grasses and those of legumes (GRAY et alii 1953); so intense was this competition between bentgrass (*Agrostis palustris*) and Ladino clover that it was found impossible with practicable rates of application of potassium fertilisers to supply the full potassium requirement of the clover when grown in association with the bentgrass. This approach may be applied to problems of rubber cultivation. Thus it has been suggested on the evidence of chemical analysis that *Mikania scandens* has a high potassium requirement; investigation of the cation exchange capacity of its roots might show whether nutrient competition is the cause of its suggested ill effects on rubber or whether some other factor is involved.

EFFECT OF COVER PLANTS ON SOIL NITROGEN

Cover plants can affect the soil nitrogen status by:

a interference with nitrification processes in the soil;

b the symbiotic fixation of nitrogen from the soil air by bacteria of the genus *Rhizobium* found in the root nodules of leguminous plants.

In addition to (*a*) and (*b*), cover plants can modify the soil nitrogen status by absorbing nitrogen from the soil, hence minimising the loss of soil nitrate by leaching This function has been discussed in the previous section.

Interference with Nitrification Processes in the Soil

Nitrification of organic matter in tropical soils can be very rapid and in dry seasons a considerable accumulation of nitrate occurs (AP GRIFFITH & MANNING 1949). Nitrate may be produced from organic residues such as dead leaf, stem, and root material by bacterial and possibly photochemical processes, or it may appear as the end product of the nitrogen fixing activities of *Azotobacter* and, perhaps, the blue green algae (MEIKLEJOHN 1955).

Some tropical grasses and plants are said to be able to suppress nitrification; in Uganda soils on which elephant grass (*Pennisetum purpureum*) and *Paspalum* spp were growing little nitrate could be detected in the top six feet (MILLS 1953). After the grass was cleared, nitrification began quite quickly in the soil that had grown elephant grass but the soil formerly under *Paspalum* took much longer to recover its nitrifying properties, and maize grown on it shortly after clearance gave a very poor yield (MEIKLEJOHN 1955). The existence of such differences is confirmed in some studies of poor nitrification in orchard soils under permanent grass which have shown that water extracts of the roots of *Panicum maximum* inhibit nitrification whereas extracts of *Sporobolus pyramidalos* do not (MARLOTH 1956). The slow decomposition of dead material and sterility of the soil under lalang (*Imperata arundinacea*) and other grasses may be due to this effect.

If nitrification of litter mixed with the top soil layer is suppressed by the presence of certain plant roots, it must be presumed that the rubber roots take up some nitrogen as ammonium or amino radicals. In this connection it is interesting to note the finding (BOLLE-JONES 1955) that rubber plants can tolerate high levels of ammonium ions and will respond rather better, in some respects, to the supply of this ion than to that of the nitrate ion.

Nitrogen Fixation by Legumes

Nitrogen fixation by leguminous plants is an established fact in temperate climates and has also been qualitatively demonstrated in pot experiments in Malaya (HAMILTON & PILLAY 1941). In New Zealand it has been found that under good conditions clover may fix about six hundred pounds per acre of nitrogen per year, and that the nitrogen needed for high production pastures is derived almost entirely from clover present in the pasture (WALKER 1956). Six hundred pounds per acre of nitrogen is more than sufficient to meet the nitrogen requirements of the rubber tree, and even assuming that considerable leaching losses occur it would seem that tropical legume plants of a similar nitrogen fixing capacity to the clovers could make a useful contribution to soil nitrogen in rubber plantations.

In the Annual Report of the Rubber Research Institute of Malaya for 1939 it is noted that inoculated *Centrosema pubescens* plants were found to contain the equivalent of 1185 lb of ammonium sulphate per acre after four months' growth in sand culture with no added nitrogen fertiliser In the Annual Report for 1952 comparisons of bare soil plots and plots covered with leguminous creeper are reported which showed that soil in the latter contained more nitrogen, the equivalent of one ton of ammonium suplhate per acre, than the former. This latter comparison makes no allowance for variations in soil nitrogen content caused by the cover plants' effect upon nitrification and leaching of nitrates, but it seems likely from these two experiments that major levels of nitrogen fixation are involved. If the findings can be confirmed strong arguments will be offered in favour of the cultivation of leguminous cover plants in rubber estates.

The low soil pH of many tropical soils has been suggested as a factor that might limit nitrogen fixation by legumes, but it has been reported (REGAL & STRAFELDA 1955) that legumes do not show any impairment of vigour or nodulation on natural sites with pH values as low as 4. Beneficial effects due to liming in their experiments are attributed to improved decomposition of organic matter rather than to an increase of pH value. Other investigations show that calcium plays an important part in legume nutrition (ALBRECHT 1933, BROWN & MUNSELL 1942), and that the concentration of available calcium needs to be relatively high to sustain an active population of the root nodule bacteria (McCALLA 1937). It would be expected that legumes and associated *Rhizobia* indigenous to the tropics would have lower calcium requirements than would leguminous plants from the lightly leached more calcareous soils of temperate climates. More recent work (HARSTON & ALBRECHT 1942) suggests that soil acidity is not detrimental, but rather beneficial to nitrogen fixation by the legume. Proper nutrient supply is found to be a more important factor than the soil acidity in ensuring satisfactory nitrogen fixation.

The provision of a satisfactory soil nutrient status for optimum nitrogen fixation by leguminous plants is by no means certain with Malayan soils. On the coastal clay type of soil generally satisfactory nutritional conditions exist, but on some of the extensive areas of sandy and lateritic soil it is possible that certain important nutrients will be at deficient levels.

Calcium is important in legume nutrition and is at a low level in many Malayan sandy and lateritic soils. Magnesium seems to play a closely analogous role to that of calcium and is known to be deficient in many soils, but potassium is only rarely deficient. Phosphorus plays a most important part in legume nutrition; it is closely connected with the metabolism of symbiotically fixed nitrogen and also greatly influences the numbers and motility of the flagellated *Rhizobia* in the soil (THORNTON & GANGULEE 1926). In most Malayan soils phosphorus is at a low level and applied phosphate is rapidly fixed, while practical experience has shown that regular dusting of the cover crop with a phosphate fertiliser is most beneficial.

Of the minor elements, molybdenum, zinc, sulphur, and copper are important in legume nutrition (ANDERSON & MOYE 1952, MULDER 1950, JENSEN 1949) and all can be expected to occur at limiting deficiency levels under certain Malayan soil conditions (GREENE 1954). Molybdenum and zinc may be segregated in relatively unavailable form together with iron in the formation of lateritic soils (PRESCOTT & PENDLETON 1952); a response by leguminous cover plants to applications of these two elements on Malayan soils has been reported (FLINT 1930, SANDISON & HANLEY 1954).

Australian work suggests (WALKER 1955) that sulphur deficiency may be widespread in areas growing tropical legumes. No information is available concerning such an effect in Malaya but since under conditions of moderate to high rainfall soil sulphur is retained chiefly in the organic matter fraction (DURING 1955) the more sandy soils, low in organic matter, are likely to contain low levels of this element.

In some of the leached siliceous sands of Australia, zinc and copper deficiencies are found associated (RICEMAN 1949, ROSSITER 1951) but little information is available on the copper status of Malayan soils.

Nitrogen fixation by leguminous cover plants is not assured merely by providing the correct nutritional conditions. The fixation depends upon the symbiotic association of root nodule bacteria with the legume, the plant leaves supplying carbohydrate and the bacteria supplying nitrogen. Infection of the legume roots by nodule bacteria in the soil results in the rapid division of cortical root cells and characteristic nodules are formed (RUSSELL 1950a). Within these nodules a process of development

and decay of both host and bacterial cells proceeds, the bacteria exhibiting several different forms (Thornton 1954). The actual nitrogen fixation process is associated with the development of haemoglobin and methaemoglobin pigments together with a third green pigment containing iron, related to bile pigments formed from haemoglobin in animals, but the actual function of these pigments remains unexplained (Virtanen & Laine 1946, Keilin & Smith 1947).

In an active nodule, elaborated compounds containing nitrogen fixed from the soil air are either excreted into the soil or are taken up by the plant tissues. It has been found in some experiments that as much as 60 to 70% of the nitrogen gained by fixation is excreted (Wyss & Wilson 1941) whilst in soya beans there is a continuous transfer of nitrogen from the nodules into the plant, most of the fixed nitrogen passing from the bacteria without appreciable delay (Bond 1936). The quantity in which nitrogen is fixed, and its eventual fate, is intimately connected with the growth rate of the plant. Satisfactory plant growth demands the maintenance of an optimum carbohydrate/nitrogen balance in the sap, so that, under normal conditions of photosynthesis where the carbohydrate supply to the plant roots and nodules is assured, an effective symbiotic association will permit the fixation of nitrogen at a rate which maintains the carbohydrate/nitrogen balance. If photosynthesis increases, carbohydrate supply is increased and the nitrogen demand is raised accordingly; if carbohydrate falls to a low level, or alternately if extraneous sources of nitrogen are freely available, the carbon/nitrogen ratio decreases and the rate of fixation is depressed until it may cease entirely. The operation of this balance may largely direct the fate of fixed nitrogen. Under cool climatic conditions excretion of fixed nitrogen has been found particularly as aspartic acid and alanine (Virtanen & Laine 1939, Thornton 1954) and it is possible that this is the result of low photosynthetic activity, causing an unbalanced carbon/nitrogen ratio. With the high temperatures and long hours of sunshine of the tropics the carbon/nitrogen ratio is thought to remain sufficiently high to preclude possibilities of significant excretion of nitrogenous compounds (Whyte et alii 1953). If this is so, fixed nitrogen can only become available to plants growing in association with the legumes after the mineralisation of the dead leaf, stem and root material returned to the soil.

This last suggestion leads to consideration of the possibility of taking advantage of the nitrogen fixing properties of the legumes by ploughing them in as green manures. Such cultivation has been proposed or carried out at various times according to the Reports of the Rubber Research Institute of Malaya (1930, 1939, 1941-5, also Wilshaw 1934) but as this text is primarily concerned with the long term association of semi-permanent cover plants with rubber, a discussion of the comparative values of legumes and non-legumes as green manures cannot be undertaken. It should be borne in mind however that the ploughing in of cover plants introduces a number of problems regarding plant succession, apart from the immediate effects on soil conditions.

A point of incidental interest to the subject of excretion of nitrogenous compounds is that under certain conditions a non-legume (wheat) has been shown to excrete a variety of such compounds (Tesar & Kutacek 1955, Katznelson et alii 1955).

The question of nodulation and subsequent nitrogen fixation is not a simple one. Approximately 90% of legumes are capable of forming nodules (Allen & Allen 1950, Allen & Baldwin 1954) but even a legume species capable of nodulation cannot form nodules unless the right strain of *Rhizobium* is present (Meiklejohn 1955). The genus *Rhizobium* has been divided into several 'species.' Each species is characterised by its capacity to form nodules on a given group of legumes (Fred et alii 1932). There are for example clover, lucerne, and pea *Rhizobia* each

forming nodules on a few legume species. The rigidity of such a classification is questioned however as bacteria have been found that can effectively nodulate legumes from different groups (WILSON 1944, THORNTON 1954). If a legume cover plant is indigenous, or established in the country for many years, a satisfactory strain of *Rhizobium* will nearly always be present in the soil; however a newly introduced legume requires to have its seed inoculated with a suitable strain of *Rhizobium* if good growth is to be depended upon. Furthermore strains of *Rhizobium* even within one of the main groups vary a great deal in the effectiveness with which they operate in the nitrogen fixing process (THORNTON 1954). Leguminous weeds in the tropics often belong to genera which contain nodule forming species, but it is not known if the weeds bear nodules nor, if they do, whether the nodules contain effective bacteria (MEIKLEJOHN 1955). If a legume were newly introduced and grown without prior seed inoculation, it would be possible for the plant to be infected with inefficient bacteria from the local leguminous weeds. In such a case the roots of the new legumes might possess many nodules but the plant would add nothing to the nitrogen supply of the soil and a potentially valuable species might be dismissed as useless.

Even if legume seeds are inoculated with an effective strain of *Rhizobium* the cultivated strains must compete after sowing with the wild strains which exist in the soil. Strains of *Rhizobium* appear to differ greatly in their ability to infect the plant roots and even though the inoculated bacteria may be advantageously placed their numbers are often small compared with the number of wild *Rhizobium* strains present in the soil (WILSON 1926) and complete infection with the desired strain cannot be guaranteed (THORNTON 1954). In this connection inoculation of the soil with an effective strain has been reported to be more effective than inoculation of the seed (MARLOTH 1956).

Inoculation processes, which involve pre-soaking of the seed, make the seed sensitive to dry soil conditions and many planters do not bother to inoculate their seed. How far subsequent disappointing growth can be ascribed to this omission could only be answered by detailed study of the nodules found on the resulting legume roots.

EFFECT OF COVER PLANTS ON SOIL MOISTURE

Despite the fact that Malaya has an annual rainfall of some 100 inches with no pronounced wet and dry seasons, soil moisture content can sometimes fall to growth limiting levels and water conservation is an important requirement, particularly on the more coarsely textured soils. This is due in large measure to the fact that most of the rain falls in heavy showers or thunderstorms and surface run-off on bare soils can be serious. With the provision of a cover such run-off can be much reduced but the extra losses of moisture caused by transpiration losses through the foliage of cover plants can, in turn, be appreciable. Some experiments in Malaya have shown that young plantings of *Centrosema pubescens* and *Mikania scandens* did not significantly reduce the soil moisture content to levels below those found under a bare surface (BELGRAVE 1930). In Ceylon, however, a comparison of the moisture content of soil under a clean weeded surface and under a cover of the creeping legume *Centrosema pubescens* showed that for the first two years after establishment of the cover there was more moisture in the first six inches of soil under the cover than in the corresponding region of the bare soil, but that the reverse was true for soil below a depth of six inches (JOACHIM et alii 1927, 1930). The greatest total moisture in the top eighteen inches was found under the bare soil. It was evident that more moisture was lost by transpiration from the cover plant than was conserved by the surface mulch it produced. However during the second two years of the experiment the mulch under the cover plant developed to such an extent that eventually more moisture was found at all levels down

to twentyfour inches under the cover plant, than under the bare surface. These findings have been confirmed (Prillwitz 1930, Simons 1955). The continued use of a non-mowing system of cultivation in grassed down orchards was found to have a cumulative retentive effect on the available soil moisture due to the addition of mulching materials and increase in organic matter content of the soil (Simons 1955).

In newly planted rubber plantations it would seem therefore that the top soil in the planting row will tend to be dry and that the reserves of water in the subsoil are likely to suffer depletion by lateral diffusion into the drying subsoil under the inter-row covered area. Both factors will contribute to drought susceptibility of the planting row and are strong arguments in favour of mulching being carried out around the young rubber trees. After the first year or two of growth, rubber roots spreading under the cover plants will be able to take full advantage of the water conserving properties of the mature cover and its litter mulch.

There is little information on the respective transpiration capacities of different cover plants. The transpiration from an actively growing crop is primarily dependent on meteorological conditions and similar amounts of transpiration will occur from different plants, placed under the same conditions, provided that both give a complete ground cover (Penman 1948). Experiments (Joachim et alii 1927, 1930) which found a greater conservation of water by a four year old cover planting than by a two year old planting, both presumably of similar transpiration capacities (Russell 1950b), seem to show that relative moisture conservation by cover plants is dependent on the capacity to produce a good water-conserving mulch. Creeping cover plants might be expected on account of this to decrease surface evaporation to a greater extent than upright covers.

On waterlogged soils cover plants are sometimes grown in an effort to dry out the soil and increase aeration, and strong woody growths with deep rooting systems might show advantages in this respect compared with the shallow rooting creepers.

COVER PLANTS AND DISEASE

Root Diseases

The common cover plants are all susceptible to one or more of the root diseases of rubber but experiments at the Rubber Research Institute of Malaya (Annual Report 1940, page 91) indicate that their presence reduces the incidence of such diseases on the rubber tree. However it is stated (Young 1955) that in Ceylon they may assist in the spread of disease if not properly controlled.

A definite danger can arise when covers are allowed to grow thickly round the base of a tree. The cool moist atmosphere under such cover plants allows the fungal mycelium to extend externally up the stem and round the collar of the tree. Under such conditions *Fomes lignosus* may rapidly ring the tree and kill it.

Leaf and Stem Diseases

The majority of cases in which leaf and stem diseases affect both cover plants and the rubber tree involve the woody plants found in forestry systems of cultivation. Some of these shrubs are susceptible to pink disease (*Corticium salmonicolor*) and need to be pruned or cut out when affected. The humid conditions found in plantations where vigorous covers have developed, particularly under the forestry system, may favour the development of leaf, stem, and tapping panel diseases. In this respect low creeping cover plants would show some advantage over the taller cover plants which interfere with the free movement of air through the plantation.

Legumes and 'Sickness'

If legumes can definitely be shown to assist rubber tree growth then attempts must be made to extend the persistence of such cover plants up to, and if possible after, maturity. At the moment planters feel discouraged from carrying out rigid maintenance of a leguminous plant cover by the feeling that the legumes will inevitably become weaker and eventually disappear as the rubber trees approach maturity. In other countries of South East Asia the persistence of leguminous cover plants in mature rubber plantations appears to be more general than in Malaya; how far this is due to variation in fertility, climatic conditions, and other factors is however unknown.

The poor seed set found in most parts of Malaya might be a contributory cause of this lack of persistence and it would be interesting to compare the persistence of leguminous cover plants in the north of Malaya, where good seed set can be obtained, with that in other areas showing poor rates of seeding. Beneficial effects might be obtained by supplying seed to a deteriorating cover.

There is a common belief that because of the development of 'clover sickness' (VAN BAALEN & HEUBEL 1938, RUSSELL 1950c) soils may be unable to support a legume crop for more than a few years. This effect has been attributed to the accumulation in the soil of toxic substances produced by the legumes themselves (YOUNG 1955). It is stated that saponin is released into the soil by lucerne and that cotton, but not grain crops, are sensitive to saponin (MISHUSTIN & NAUMOVA 1955). In addition saponin kills many soil organisms. It may be that concentration of such substances over a period of time can adversely affect a leguminous cover plant. Such clover sickness can be remedied by heating the moist soil to 70°C or by air drying the soil in thin layers, or alternatively by adding large amounts of farmyard manure to the soil (RUSSELL 1950c). Bacteriophages which lyse the nodule bacteria in the soil have been suggested as the cause of this sickness and a remedy can often be obtained by inoculating the soil with a new and vigorous strain of *Rhizobium* (DEMOLON & DUNEZ 1935, 1939). Benefits obtained from periodic applications of phosphate fertiliser to leguminous cover plants may, in part, be due to the phosphate's effect in maintaining the numbers and motility of the *Rhizobia* (THORNTON & GANGULEE 1926) in the presence of such adverse soil conditions.

An alternative explanation for the non-persistence of legumes may be the simple one of pest accumulation. It is known that eelworms attack legume cover plants in Malaya (BEELEY 1939) and growth may be severely affected in some cases. Attacks by ladybird beetles (*Epilachna indica* Muls) and their larvae are widespread and growth is often badly affected. Such attacks could be expected to develop to an increasing extent the longer a particular cover plant is maintained on one area.

General experience in Malaya would seem to indicate that it is the development of shade and increasing competition for moisture by the maturing trees which are the main causes of the deterioration of legume cover plants after some years' growth. However there is scant information on the effect of any fertiliser and cultivation treatments carried out in order to counter those effects and the subject would seem worthy of investigation. There is evidence which shows that shade can limit growth response to added fertilisers (BLACKMAN & WILSON 1951, EVANS & MURRAY 1953) but as legumes are known to persist under mature rubber in some of the more fertile soil areas there is reason for hoping that fertiliser treatment could encourage a similar persistence in the poorer soils.

CONCLUSION

The above review has surveyed some of the factors to be considered when assessing the value of the different classes of cover plants commonly grown in rubber plantations, and also some of the difficulties encountered in cultivating the introduced legumes. Some of the problems involved in this aspect of rubber tree cultivation are under investigation at the Rubber Research Institute of Malaya.

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Bacterial Culture Media from Hevea Latex

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The availability is indicated of two bacterial growth media, at present rejected in large quantities by the natural latex industry in Malaya: details for the preparation of these for routine laboratory use are given. Some of the bacteria which have been cultured on these media are listed.

THE RAPID GROWTH OF BACTERIA in fresh hevea latex suggests that reject materials derived from this latex may serve as bacterial culture media. It is known that the activities of the fresh latex bacteria are confined, in main, to components present in the serum and are not associated with the decomposition of the dispersed hydrocarbon. Two sera are readily available from the factory; the first is 'sheet serum' formed on the (formic) acid coagulation of diluted field latex, the second is 'skim serum'. Both of these materials are good culture media for bacteria. It is the purpose of this paper to indicate the extreme utility of both as general culture media for microorganisms and to describe their preparation for routine laboratory use.

The production of latex concentrate from hevea latex by centrifuging is accompanied by the accumulation of large quantities of the low polyisoprene content dispersion known as 'skim'. The coagulation of this material is usually accomplished by lowering the pH, either by the direct addition of mineral acid or by the progressive action of bacteria principally of the genera *Streptococcus* Rosenbach, and *Propionibacterium* Orla-Jensen. In the former case there results a skim serum the pH of which varies between 4 and 5 but which otherwise possesses all the properties of a first class bacteriologic medium. This serum is, at present, rejected as a useless by-product of natural rubber production.

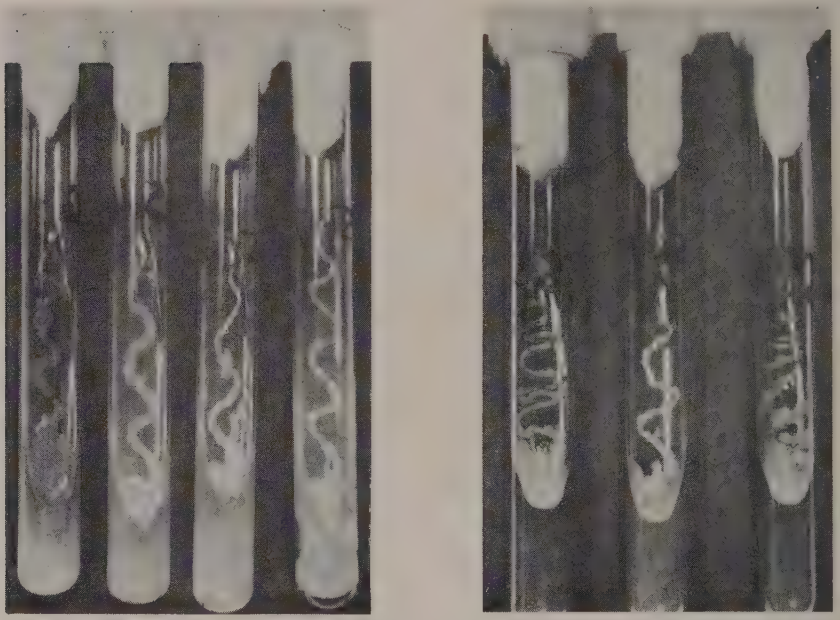
EXPERIMENTAL METHODS

Skim serum rejected in this way from the factory is bulked, its pH is adjusted roughly to 7, and it is autoclaved at a pressure of 10 lb per sq. in. for 10 minutes. On cooling, the pH is accurately adjusted to 7.0 + 0.1 by the addition of 2N aqueous sodium hydroxide. The medium is then filtered through paper pulp and sterilised at a pressure of 15 lb per sq.in. for 10 minutes. A solid medium can be obtained by the addition of agar agar; the agar is added after the rough adjustment of pH and the initial autoclaving serves to melt the agar into solution — accurate adjustment again follows on filtration through paper pulp. The final medium is a golden brown in appearance, not unlike normal (lab' lemco) nutrient agar.

The initial autoclaving serves to precipitate any hydrocarbon or protein not coagulated by the factory addition of mineral acid. The necessity for this procedure depends upon the time allowed after coagulation for the separation of serum from coagulum. It is general factory practice to allow the acidified serum to stand overnight and if this procedure is adopted, no further precipation occurs on autoclaving.

Sheet serum may be prepared for laboratory use in an exactly analogous fashion.

COMMUNICATION 302



Strains of bacteria growing aerobically on (right) skim serum agar slopes, and on (left) sheet serum agar slopes.

RESULTS

Bacteria known to grow well on these media include *Serratia marcescens* Bizio, *Bacterium mycoides* Grotenfelt, *Chromobacterium violaceum* Schroeter *Mycobacterium phlei* Lehmann & Neumann, the whole of the coliform group of organisms, staphylococci, streptococci, propionibacteria, microbacteria, bacilli, micrococci, some corynebacteria, and flavobacteria and a large variety of unidentified organisms derived from hevea latices and Malayan soils. In addition the growth of species of streptomyces has been observed. There seems no reason why the media should not be equally useful for the cultivation of fungi (*Eumycetes*).

DISCUSSION

The media contain a wide variety of amino acids principally alanine, valine, tyrosine and proline, carbohydrates mainly the polyhydric alcohols myo-inositol and quebrachitol (methyl-l-inositol), an exceedingly diverse series of proteins of widely varying molecular weights probably extending to the nuclear proteins and various plant growth factors.

Since sera are rejected from latex factories in Malaya at the rate of thousands of gallons per day, this material is available for the large scale production of antibiotics and growth factors. One example may be of value: the tripyrryl methene pigment of *Serratia marcescens* is active in vitro against various pathogenic fungi (Harned 1954, Wier et alii 1952); its production depends upon the availability of cheap culture media

for the growth of this organism. Both skim and sheet sera are excellent media for the cultivation of *S. marcescens* although no doubt the amount of pigment produced per cell can be increased by the addition of further carbohydrates.

The utilisation of sera would prevent their pollution of local river water supplies. In these, at present large numbers of bacteria are cultivated under almost ideal conditions and constitute a continual danger to the latex producer who frequently uses these contaminated waters in factory washing. The processing of sera (and factory waste in general) would thus both remove a danger and provide an asset.

Under present unhygenic factory conditions, sheet serum, despite its further dilution, has proved the better culture medium. Growth on skim serum is less luxuriant. This position could be reversed, but the reversal is unlikely under present economic conditions.

The author wishes to thank Mr D. J. Graham and Mr M. Gopal for the provision of these sera, and Mr A. S. Dhilan for much practical assistance and active cooperation. The work described arises from a microbiological investigation of natural rubber latex.

A shorter description of this work has appeared in the Journal of Applied Bacteriology 19 (1956) 60.

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A Magnesium-Manganese Interrelationship in the Mineral Nutrition of Hevea Brasiliensis

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Increased supplies of magnesium to rubber plants fed with low or normal levels of manganese produced symptoms of manganese deficiency and reduced the concentration of manganese found in the laminae. At the lower levels of magnesium supply an increased concentration of magnesium in the laminae was accompanied by a decrease in that of manganese. At a luxury level of magnesium supply an increase in the magnesium concentration was accompanied by a similar increase in that of manganese.

DEFICIENCY SYMPTOMS OF BOTH MAGNESIUM AND MANGANESE, in *Hevea brasiliensis*, occur in Malaya. Magnesium deficiency is widespread and can cause a marked retardation in growth; the occurrence and severity of manganese deficiency in the field is not yet fully known as a description of the leaf symptoms was not published until recently (Bolle-Jones 1954b). The highly acid nature of Malayan soils makes probable a high available manganese content; the possibility that this was involved in the production of the magnesium deficiency warranted investigation. It was already known that manganese may accumulate to some extent in the laminae of magnesium deficient plants (Bolle-Jones 1954b) and that increasing levels of magnesium consistently decreased the manganese concentration of the laminae (Bolle-Jones 1954c). Further confirmation of this effect was necessary. To this end, the influence of magnesium status on the concentration of manganese in the laminae of plants grown at varying levels of manganese supply was investigated.

Beaufils (1955) has stated that a highly significant, positive, direct correlation existed between the magnesium and manganese concentrations found in leaves of *Hevea brasiliensis*. However, apart from this reference and those given above there is no information regarding the interrelationship of magnesium and manganese in the nutrition of *Hevea brasiliensis* and, apart from their effect on enzyme activity, little is reported in the general literature.

Swanback (1939) concluded that manganese (as well as potassium and calcium) antagonised the absorption of magnesium by tobacco plants and it can be tentatively inferred from his data that an increase in manganese level decreased the uptake of magnesium. Loustalot, Winters and Childers (1947) grew cinchona seedlings under high soil moisture conditions; the seedlings developed symptoms which resembled magnesium deficiency or manganese toxicity in other plants. This lack of definite characterisation may have implied the presence of both types of symptom and a possible interrelationship between the elements. Plant (1953) showed, by the use of indicator crops, that plants grown on acid soils developed magnesium deficiency symptoms and that these were usually accompanied by either manganese or aluminium toxicity effects or both. He concluded that a reduction of manganese content, as effected by liming, was associated with an increased magnesium content although this increase was not convincingly illustrated in his analytical results. Mulder and

GERRETSEN (1952) have also pointed out that magnesium deficiency develops in plants grown on acid soils which contain large amounts of available manganese.

There is therefore some evidence which indicates that magnesium deficiency may be sometimes associated with manganese toxicity effects but no indication that magnesium level may affect the manganese status of the plant. The present experiment carried out in sand culture revealed that both elements were closely interrelated in the nutrition of *Hevea*. Increasing supplies of magnesium consistently decreased the manganese concentration of the laminae from any stem position while the effect of increasing manganese level was to decrease the magnesium concentration of laminae taken from the top storeys.

EXPERIMENTAL

Hevea brasiliensis seedlings, clone Tjir 1, were grown in a pot sand culture experiment in which magnesium and manganese were each applied at three levels, to give a total of nine treatments. The levels used represented low or deficiency (Mg_1 and Mn_1), normal (Mg_2 and Mn_2) and high (Mg_3 and Mn_3) rates of application:

Milligram equivalents per litre

Mg_1	... 0.4	Mn_1	... 0.0005 (approx)
Mg_2	... 1.6	Mn_2	... 0.05
Mg_3	... 6.4	Mn_3	... 1.00

For the first part of the experiment, until September 1954, nitrate, phosphate, potassium and calcium ions were supplied at 7, 3, 4 and 1 milligram equivalents per litre, respectively. Later it was found necessary, owing to the appearance of iron deficiency effects to alter the nutrient composition to the following levels (in m.eq./l): NO_3^- 5.0; NH_4^+ 3.0; PO_4^{---} 3.0; K^+ 3.0; Ca^{++} 4.0. In addition, sodium was supplied at 1.0 m.eq./l and sulphate varied between 5 and 12 m.eq./l, the concentration increasing with magnesium level. Throughout the experiment iron, boron, copper, zinc and molybdenum were supplied at the rate of 17, 0.07, 0.06, 0.06 and 0.02 parts per million, respectively. The sand used in this experiment had been washed with hydrochloric acid and was contained either in pyrex glass pots (Mn_1) or in bitumen painted, five gallon clay pots (Mn_2 and Mn_3). Each treatment was duplicated and each replicate contained three pots.

Thirteen 'selfed' seeds of clone Tjirandi 1 were sown in each pot in March 1954: subsequently, in the following April, June, August and November the seedlings were progressively removed for analysis until in April 1955 — the time of the final harvesting — one plant only remained.

At each sampling the total dry weight per plant per treatment was recorded and the following values determined: percentage rubber in the green portion of the stems, concentrations of magnesium, potassium, calcium, phosphorus and manganese in the laminae. The analytical procedures employed have been described (BOLLE-JONES 1954a). The leaves for analysis, were removed from definite storey positions; the midrib was excised and discarded and the remainder of the lamina used for analysis. Not all the results of analyses are reported below but only a representative few of those collected.

Figure 1. Mg_2 Mn_1 (*left*); Mg_1 Mn_1 (*right*). *Note clear symptoms of manganese deficiency in left hand plant as a result of increased magnesium level. Plants twelve months old.*

RESULTS

Visual Observations

Deficiency symptoms of manganese were observed in April before those of magnesium, which did not appear until May. The manganese deficiency symptoms first occurred in the Mn_1 plants, but were observed later in October and November, in the Mn_2 plants, particularly at the higher Mg levels. It did in fact appear that increased magnesium level could induce a deficiency of manganese (*Figure 1*).

Magnesium deficiency symptoms were mainly confined to the Mg_1 plants but some slight symptoms were observed in the Mg_2 plants at the higher manganese levels. The magnesium deficiency symptoms occurred more frequently in plants of the higher (than of the low) manganese treatments.

Some symptoms, suspected to be those of iron deficiency, appeared, in August, in the Mg_3 Mn_3 plants. To avoid rapid deterioration of all plants in the Mg_2 and Mg_3 treatments and to give a better and more vigorous growth the composition of the nutrient was changed (as indicated above); as a result, much healthier growth was obtained.

TABLE 1. TOTAL DRY WEIGHT PER PLANT
(*grams*)

	April 1954			*August 1954*			*April 1955*		
Level	Mn_1	Mn_2	Mn_3	Mn_1	Mn_2	Mn_3	Mn_1	Mn_2	Mn_3
		(± 0.10)			(± 1.4)			(± 54)	
Mg_1	1.0	1.4	1.2	7.6	7.6	10.3	484	396	416
Mg_2	0.9	1.3	1.3	18.2	15.4	18.0	472	494	523
Mg_3	1.0	1.2	1.3	20.5	18.2	20.7	476	528	358

Dry Weight Per Complete Plant (Table 1)

The dry weight of month old seedlings significantly increased with manganese supply but little effect of magnesium was observed. However, by the June sampling, magnesium seemed to limit growth more than manganese and the results given for August (Table 1) show a very significant positive effect of magnesium, but none of manganese, on dry weight production. The final sampling, made a year after sowing, showed no significant effect attributable either to magnesium or manganese.

Thus for the first two or three months of the seedlings development manganese seemed to be required more than magnesium but later, up to the eight months stage, the predominant requirement was for magnesium.

TABLE 2. CHEMICAL COMPOSITION OF LAMINAE

	April 1954 Top Storey			August 1954 2nd Storey			November 1954 Top & 2nd Storey			April 1955 Top & 2nd Storey		
MAGNESIUM IN DRY LAMINA %												
Level	Mn_1	Mn_2 (± 0.019)	Mn_3	Mn_1	Mn_2 (± 0.022)	Mn_3	Mn_1	Mn_2 (± 0.015)	Mn_3	Mn_1	Mn_2 (± 0.015)	Mn_3
Mg_1	0.24	0.16	0.18	0.09	0.10	0.12	0.12	0.10	0.10	0.14	0.10	0.08
Mg_2	0.26	0.20	0.20	0.19	0.20	0.16	0.28	0.20	0.22	0.23	0.20	0.18
Mg_3	0.30	0.28	0.26	0.36	0.39	0.42	0.32	0.34	0.32	0.28	0.31	0.26
MANGANESE IN DRY LAMINA, P.P.M.												
Level	Mn_1	Mn_2 (± 2.5)	Mn_3	Mn_1	Mn_2 (± 3.8)	Mn_3	Mn_1	Mn_2 (± 48)	Mn_3	Mn_1	Mn_2 (± 66)	Mn_3
Mg_1	14	13	32	36	24	74	122	325	1037	25	324	2306
Mg_2	16	16	27	14	18	56	49	138	592	24	196	1190
Mg_3	10	12	30	8	12	44	37	118	324	13	172	673
PHOSPHORUS IN DRY LAMINA, %												
Level	Mn_1	Mn_2 (± 0.022)	Mn_3	Mn_1	Mn_2 (± 0.028)	Mn_3	Mn_1	Mn_2 (± 0.037)	Mn_3	Mn_1	Mn_2 (± 0.029)	Mn_3
Mg_1	0.37	0.28	0.27	0.34	0.25	0.20	0.40	0.36	0.26	0.38	0.37	0.43
Mg_2	0.40	0.28	0.27	0.27	0.25	0.20	0.42	0.32	0.30	0.34	0.32	0.31
Mg_3	0.39	0.28	0.30	0.25	0.22	0.24	0.41	0.29	0.38	0.43	0.34	0.34
POTASSIUM IN DRY LAMINA, %												
Level	Mn_1	Mn_2 (± 0.11)	Mn_3	Mn_1	Mn_2 (± 0.14)	Mn_3	Mn_1	Mn_2 (± 0.10)	Mn_3	Mn_1	Mn_2 (± 0.08)	Mn_3
Mg_1	1.4	1.3	1.2	3.2	3.1	3.1	1.7	1.4	1.4	1.4	1.6	1.3
Mg_2	1.4	1.2	1.1	2.6	3.0	2.6	1.1	1.2	1.2	1.2	1.0	1.1
Mg_3	1.4	1.3	1.2	2.0	1.5	1.5	1.0	1.1	1.0	1.0	0.8	1.0
CALCIUM IN DRY LAMINA, %												
Level	Mn_1	Mn_2 (± 0.014)	Mn_3	Mn_1	Mn_2 (± 0.052)	Mn_3	Mn_1	Mn_2 (± 0.068)	Mn_3	Mn_1	Mn_2 (± 0.061)	Mn_3
Mg_1	0.07	0.04	0.06	0.56	0.48	0.50	1.14	0.94	0.90	0.70	0.95	1.04
Mg_2	0.14	0.09	0.06	0.49	0.44	0.50	0.94	0.64	0.57	0.58	0.66	0.60
Mg_3	0.14	0.10	0.10	0.43	0.47	0.52	0.57	0.53	0.51	0.53	0.53	0.41

IRON IN DRY LAMINA, P.P.M.

Level	Mn_1	Mn_2 (± 4.7)	Mn_3
Mg_1	97	84	74
Mg_2	90	80	62
Mg_3	89	76	66

Analytical Data (Table 2)

Rubber was determined in stems, petioles and laminae but no consistent effect of mineral status on the concentration of rubber in the tissues was found. Neither was any significant effect of mineral supply on the chlorophyll content of the laminae observed, although, in general, an increased supply of magnesium tended to increase and of manganese, decrease, the values obtained.

Increased magnesium supply always and markedly increased the concentration of magnesium found in the leaves, this effect became more marked with time, as the Mg_1 plants became progressively more magnesium deficient. Samples, which contained laminae taken from the top storey, showed, one month and thirteen months after planting, a significant reduction in magnesium concentration due to increased levels of supply of manganese. This effect was always most marked at the lower Mg levels; it was also detectable for the November sampling but was not observed for the June and August samplings. The leaves sampled in June and August were taken predominantly from the second storey, whereas the remainder of the samplings included top storey leaves; thus the suppressing effect of manganese on the accumulation of magnesium was only detectable in samples which included top storey leaves.

Increased supplies of manganese consistently increased the concentration of manganese found in the laminae. For the earlier samplings, the Mn_3 laminae contained roughly twice or thrice the concentration found in Mn_1 laminae but later, after the change to the ammonium type nutrient, this differential increased to fifty or more times. For all samplings, except the first, it was found that increased levels of magnesium significantly reduced the concentration of manganese in the laminae. This effect was highly consistent and became more marked with time. There was ample evidence to suggest that at low levels of supply of manganese the addition of an excess of magnesium can cause a severe deficiency of manganese to arise.

Laminae sampled up to and including November showed a significant reduction in their concentration of phosphorus as a result of manganese addition; this effect of manganese was usually most marked at the lower magnesium levels. Generally, magnesium addition was not observed to produce a consistent effect on the laminar phosphorus concentration. An increased supply of magnesium usually decreased the concentration of potassium and calcium in the laminae. For the earlier samplings increased manganese supply also reduced the calcium concentration within the laminae. The iron concentration of the laminae was determined for the material harvested in April 1955; it was found that increased manganese level significantly reduced the concentration of iron in the laminae.

DISCUSSION

Both the visual observations and the analytical data support the idea that magnesium and manganese are directly related in the nutrition of the rubber plant. Thus, increased supplies of magnesium markedly diminished the concentration of manganese in the laminae and induced the appearance of manganese deficiency symptoms. Some of the data also showed that increased manganese supply could reduce the magnesium concentration of the upper laminae; this effect was sometimes, but not always, accompanied by the appearance of magnesium deficiency symptoms. These findings are not in apparent accord with the direct magnesium-manganese correlationship reported by Beaufils (1955) for field grown plants.

When the manganese and magnesium concentrations, found in the laminae were plotted against one another certain trends were noted. Thus, for the samplings taken at the time of nitrate nutrient supply (*Figure 2*), an increased concentration of

magnesium in the laminae of the Mg_1 and Mg_2 plants was accompanied by a decrease in that of manganese. However, for the Mg_3 plants evidence of the opposite effect was obtained; that is, an increase in the manganese occurred as the magnesium concentration increased. Similar trends were noted for the samplings taken from plants supplied with the ammonium type nutrient (*Figure* 3). A marked, almost linear decline in manganese concentration was observed for the Mg_1 plants with increasing magnesium, and of a tendency for a limited increase in manganese concentration with increased magnesium at the Mg_3 level. The relationship obtained for the Mg_2 plants seemed intermediate between the effects observed for the Mg_1 and Mg_3 plants. Thus the nature of these main effects was not altered as a result of the change in nutrient composition.

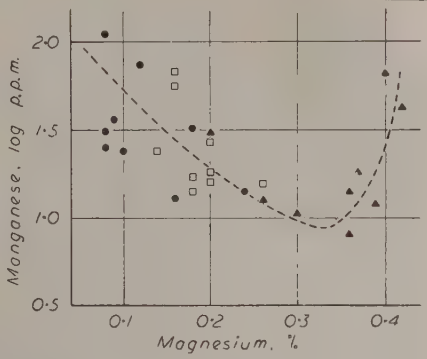

Figure 2. Relationships between the concentrations of manganese and magnesium found in the dry laminae of plants sampled in April, June and August 1954

Mg_1 • Mg_2 ▫ Mg_3 ▲

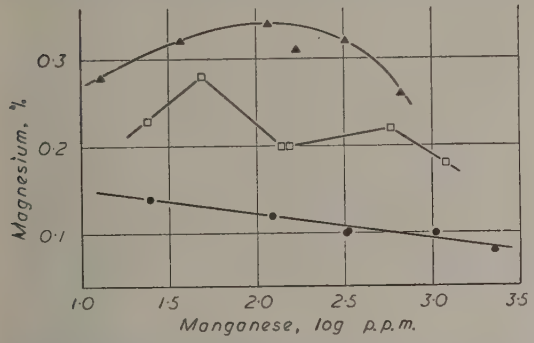

Figure 3. Relationships between the concentrations of manganese and magnesium found in the dry laminae of plants sampled in November 1954 and April 1955. Note linear negative relationship obtained at the Mg_1 level.

Mg_1 • Mg_2 ▫ Mg_3 ▲

The ease of identification of magnesium deficiency symptoms permits the rough assessment of the occurrence of the deficiency, and of the conclusion that it occurs extensively in Malaya, especially on replanted areas. Commonly, the remedial measure for the deficiency is the application of magnesium limestone. Both the calcium and magnesium constitutents of this limestone may depress the manganses uptake of the laminae. As there are indications that manganese deficiency, in a mild or incipient form, is quite common in Malayan rubber plantations, it may ultimately prove necessary, to supply a manganese supplement at the same time as the magnesium limestone is applied. Whether such action might prove necessary will depend on a full evaluation of the occurrence and severity of manganese deficiency symptoms and on the finding of whether, under normal estate conditions, these symptoms cause a marked diminution in growth and yield of rubber per tree.

An enhanced supply of manganese not only influenced magnesium status but also reduced the concentration of iron and phosphorus found in the laminae. The effect of manganese level on iron concentration is in agreement with observations, reported by other workers (Wallace & Hewitt 1946) who have shown that nutrients possessing a high Mn/Fe ratio, may produce iron deficiency effects. However, the effect of

manganese, a micronutrient, on the accumulation of phosphorus, a macronutrient, in the laminae, is not generally known. The results reported here show a definite decrease in phosphorus concentration as the manganese supply to the plant increased. Increased phosphorus supply may decrease the laminar concentration of manganese found for potato (Bolle-Jones 1955) but increase that found for rubber (Bolle-Jones 1954c); why such a difference of behaviour between the two plants should exist is difficult to explain and confirmation of these trends is required. However, there seems little doubt on the basis of these reports that both manganese and phosphorus are closely interrelated in the mineral nutrition of plants.

Earlier work (Bolle-Jones 1954c) showed that increased magnesium supply influenced, usually increased, the phosphorus concentration of the lamina and that, for the earlier stages of the seedlings development, growth seemed to be governed more by the supply of magnesium than by phosphate. The present study shows that the concentration of manganese in the laminae is closely related to the magnesium status of the plant, that the level of manganese supply may influence the amount of phosphorus found in the lamina, and that growth is limited more by manganese than by magnesium in the early stages of development. Therefore it would seem that not only are the three elements closely connected but the requirement for an adequate external supply of manganese takes priority over that of magnesium which, in turn, is required more than phosphorus during the earlier stages of seedling development. This situation could be caused by relatively low reserves of manganese stored in the seed as compared with those of magnesium and phosphorus.

SUMMARY

Seedlings of *Hevea brasiliensis* were grown in sand culture at low, normal and high levels of magnesium and manganese. Increased levels of supply of magnesium induced the appearance of manganese deficiency symptoms in plants supplied with the lower levels of manganese and significantly reduced the concentration of manganese found in the laminae of those plants. The concentration of magnesium found in the upper laminae decreased as the nutrient supply of manganese increased and, in consequence, symptoms of magnesium deficiency were sometimes produced. At the lower levels of magnesium supply, it was shown that with an increased concentration of magnesium in the laminae the concentration of manganese decreased. At the high or 'luxury' level of magnesium supply an increase in the concentration of magnesium in the laminae was accompanied by an increase in the manganese concentration. The suggestion was made that in the early stages of the rubber seedling's development the requirement for an external supply of manganese was more important than that of magnesium which, in turn, was required more than phosphorus; these relative requirements may be related to the amount of mineral reserves present in the seed.

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Manuring Hevea: Effects of Fertilisers on Growth and Yield of Mature Rubber Trees

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Combined results of seventeen manuring experiments on rubber trees in Malaya are presented and the effects of fertilisers on growth and yield of rubber are discussed. The main effect is shown to be due to applications of nitrogen in the presence of potassium, and to applications of phosphate. Responses on inland soil types and on coastal alluvial soils are compared. The influence on the post-war manuring effects of treatments applied pre-war, when the trees were immature, has been examined.

THE MANURING EXPERIMENTS TO BE DESCRIBED and discussed are some of those which were laid down on rubber estates in different parts of Malaya in the period 1935 to 1938. These experiments are listed and relevant particulars are summarised in Table 1. All except one (No 3) started as experiments from the time of planting, either as replantings or as new plantings on land cleared from lalang (*Imperata cylindrica*) or from jungle. In experiment No 3 the trees were already 10 years old when the experimental manuring treatment was started in 1938. In all other experiments, fertiliser treatments commenced at the time of planting and were continued up to 1941 when the war intervened.

The experiments are sited on a variety of soil types in different parts of the rubber growing districts of Malaya. Of the 17 experiments under consideration three are in Perak, five in Selangor, five in Johore and one in each of the following states — Kedah, Kelantan, Negri Sembilan and Pahang. The early history of 14 of these experiments has been described, and effects of the pre-war manuring treatments on early growth have been discussed in an earlier report (AKHURST & OWEN 1950). A more detailed statistical interpretation of the results from the same experiments was given in a separate report (FAIRFIELD SMITH 1950). The early planting history of the remaining three experiments Nos 3, 8 and 15, not described in the earlier papers, was very similar and calls for no special comments.

The selection of the 17 experiments for discussion in this report was determined largely by the fact that they have similar fertiliser treatments and that yield records were obtained over a period which is approximately the same in each experiment, thus facilitating analysis of combined data. Several other manuring experiments in rubber areas of similar age are in progress but these are not included in this report because their treatment effects could not be compared readily or because yield records over a four year period up to 1954 were incomplete.

The experiments described fall into three groups according to design of layout. The first group consists of nine trials each having a factorial 2^3 NPK design; six of these are arranged in randomised blocks, but No 4 is in eight sub-blocks of four plots whereby the NPK effect is confounded, and the remaining two trials (Nos 5 and 8) are arranged in twelve sub-blocks of four plots so that NK and NPK effects respectively are confounded. One experiment has only two replications while the remainder have four, five or six replications.

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Table 1. Particulars of Manuring Trials

	Trial	Estate		Planting	Plot (acres)	Replications	New or replant	Soil group	Opened for tapping	Tapping system	Post-war manuring commenced	Recording period covered — Yields	Recording period covered — Girth incr't	Planting material
2^3 NPK Series	1	Banir	C	1937	1.0	5	N	inland	1946	S/1. d/4. 100%	1947	1950-54	1948-54	Tjir 1, PB 86
	2	Batu Anam	BA	1938†	1.0	5	N	"	1947	S/2. d/2. 100%	1947	1949-53	1947-53	Tjir 1, PB 86
	3	Bukit Panjong		1928†	0.5	2	R	coastal	1934	S/2. d/2. 100%	1948	1950-54	1948-54	Tjir 1
	4	Huntly	K	1937	1.5	4	N	"	1947	S/2. d/2. 100%	1947	1949-53	1947-53	Tjir 1, PB 86, Pil B84, Gl 1
	5	Mengkibol	H	1937	1.4	6	N	inland	1946	S/2. d/2. 100%	1948	1950-54	1948-54	Tjir 1, PB 86, Gl 1
	6	North Labis	B	1937	1.0	5	N	"	1947	S/2. d/2. 100%	1947	1949-53	1948-54	Tjir 1, PB 86
	7	Sedenak	Sed	1937	0.5	4	R	"	1948	S/2. d/2. 100%	1947	1949-53	1947-53	Pil B84
	8	Tebing Tinggi		1938	1.0	6	N	"	1947	S/2. d/2. 100%	1948	1950-54	1948-54	Tjir 1, PB 86, Pil B84
	9	Wardieburn	RW 3	1937	0.5	5	R	"	1946	S/2. d/2. 100%	1948	1950-54	1948-54	Tjir 1
Six-Treatment Series	10	RRI Expt Stn	F 31	1935	1.1	6	N	inland	1947	S/1. d/4. 100%	1947	1950-53	1948-53	Tjir 1, PB 86, Pil B84, Pil D65, BD5
	11	Bukit Rajah	L	1937†	2.0	6	N	coastal	1948	S/2. d/2. 100%	1948	1950-54	1948-54	PB 86, Pil B84, Gl 1, Pil D65, BD5
	12	Rengam	D	1937	1.5	6	N	inland	1947	S/2. d/2. 100%	1948	1950-54	1948-54	Tjir 1, PB 86, Pil B84
	13	Sungei Kawang	E	1937	1.5	6	N	"	1947	S/2. d/2. 100%	1948	1950-54	1948-54	Tjir 1, PB 86, Pil B84
	14	Victoria	F	1937	1.5	6	N	"	1947	S/2. d/2. 100%	1948	1950-54	1948-54	Tjir 1, PB 86, Pil B84, Pil D65
3^3 NPK Series	15	Bukit Cloh		1937†	0.5	1	R	coastal	1946	S/2. d/2. 100%§	1948	1950-54	1948-54	Tjir 1, Pil D65, PB 186
	16	Juasseh	M	1938‡	0.5	1	N	inland	1946	S/2. d/3. 67%	1947	1950-53	1948-54	P.B.I.C. clonal seedlings
	17	Ratanui	O	1938	1.5	1	N	coastal	1947	S/2. d/2. 100%	1947	1950-54	1948-54	PB 86, Pil B84, Pil D65

Letters after names of estates are key letters used in 'Manuring Experiments on Young Rubber Trees' (Akhurst & Owen 1950), in which the effect of fertilisers on early growth in 23 experiments is discussed. Later results from 14 of these experiments are included in the combined data discussed in the present report.

† Planted as budded stumps.

‡ Clonal seedlings planted

§ Tapping system was S/1 . d/4 . 100% up to March 1950. Tapping then continued on system S/2. d/2. 100%.

The second group consists of five trials each having a latin square design with six treatments, namely n, np, nk, pk, npk, and control. The remaining group includes only three trials each of which is a 3^3 NPK design consisting of 27 plots arranged in three blocks of 9 plots so that the NPK effect is confounded. Each factor occurs at three levels (0, 1 and 2) but only the first two levels are considered here since they correspond to the levels of application in the 2^3 NPK and six-treatment groups.

Plot size varies from one half of an acre to two acres. Planting density at time of planting varied from 117 to 217 planting points per acre although only three trials had an initial stand of less than 180 per acre. Tree density was reduced gradually by natural causes during the years of immaturity, and in those areas where the stand exceeded 160 per acre at time of opening up for tapping, thinning out was done then to reduce the density to approximately that figure. Further losses have since occurred, either through root disease or windstorms, and the mean stand per acre in 1954 in the different trials ranged from 82 to 156 trees per acre.

Pre-war History — Four of the experimental areas are replantings, one (No 1) is a new planting on land cleared from lalang and twelve are new plantings on land cleared from jungle. One area was planted with clonal seedlings (No 16), four with budded stumps (Nos 2, 3, 11 and 15) while the remaining twelve areas were planted with unselected seeds and the plants budded in the field a year or more later. The clones used were principally Tjirandji 1, Prang Besar 86 and Pilmoor B84, but the majority of the trials were budded with two or more clones, arranged either in strips within plots or in complete blocks, and some of these areas include other clones such as Glenshiel 1, Pilmoor D65, Bodjong Datar 5 or Prang Besar 186.

Five experiments are sited on the coastal alluvial flats where the soil is either a heavy clay or peaty loam over clay. One trial (No 1) is on inland alluvial soil and the remaining eleven trials are on undulating or hilly land with residual soils derived either from granite, sandstone, shales or phyllites. For purposes of discussing the combined results of the manuring experiments the soil types occurring in these areas are classified broadly into two groups, the coastal alluvial soils, and the inland soil types.

One of the experiments started in 1935, eleven in 1937 and five in 1938. A high standard of upkeep was maintained and fertiliser treatments were applied regularly in all areas up to 1941. During the war years no manuring was done and the areas were more or less completely abandoned. In spite of this the experimental areas on the whole came through with surprisingly little damage.

Post-war History — Following re-occupation of the country in 1945 the work of rehabilitating all rubber areas, including the experiments, was carried out. Plots were again identified and girths of trees were measured. By this time the majority of the trees in all areas had reached tappable size and all experiments were opened up for tapping at some time during the first three years after re-occupation of the country. The tapping system employed in most of the experiments was the half circumference spiral cut alternate daily (S/2 . d/2 . 100%). Exceptions are experiments Nos 1 and 10, which were tapped on full circumference spiral every fourth day (S/1 . d/4 . 100%), and No 16, planted with clonal seedlings, where the tapping system was half circumference spiral third daily (S/2 . d/3 . 67%). Trial No 15 was opened up for tapping in 1946 on the S/1 . d/4 . 100% system but this was changed to S/2 . d/2 . 100% in March 1950.

In all except one of the 17 experiments the manuring schedule was resumed according to the original plan, the design remaining unchanged. Experiment No 5 was originally a six-treatment design but was amended on resumption after the war. Post-war applications of fertilisers here were made according to the 2^3 NPK design (12 sub-blocks of 4 plots, NK confounded) and the present yield and girth increment data have

been analysed on this basis after first examining for effects associated with the earlier manuring programme.

Other minor changes became necessary after resumption in the post-war period. Experiment No 12, which started as a 6×6 latin square, had to be reduced to a randomised block with only 4 replications in 1951 owing to severe wilful damage to trees in a part of the area caused by terrorists. A similar modification became necessary in trial No 1 due to discovery of rogue clones in one of the five blocks after three years of post-war recording of girth measurements. The data from these two experiments have been summarised again so that all values relate to four blocks only.

Girths were measured annually on numbered trees at a specified height, usually 60 inches above ground, starting either in 1947 or 1948. All trees except those in boundary rows were usually measured; trees in alternate rows only were measured in two trials. For yield recording the standard method in experiments on estates was to mark twenty-five trees in the centre of each main plot, or ten trees in clonal sub-plots, and to coagulate the latex from these marked trees, in the cups, on one tapping day in each month up to January 1954, and once every second month thereafter. The coagulated samples from each plot separately were collected, rolled or flattened, dried in the smoke house for ten days and weighed. Where facilities for smoke drying were not available, the samples were air dried for thirty days before weighing. On most estates a Chinese daching was used for weighing the dried rubber samples which explains why yields are expressed in tahils per tree per tapping (1 tahil = $1\frac{1}{3}$ oz = 38 grams).

A different procedure was followed in experiment No 10. Here, the latex from all trees in the plot was coagulated in the cups on two tapping days per month. The coagulated lumps were milled and made into crepe sheets which were dried and weighed.

Fertiliser treatments were resumed after the war in the various trials at different times between July 1947 and June 1948. Fertilisers used for experimental manuring treatments were sulphate of ammonia, Christmas Island rock phosphate and muriate of potash at rates of 2.4, 1.2 and 0.4 lb per tree per application respectively in the 2^3 NPK series and the six-treatment series, while the same amounts were the unit levels in the 3^3 NPK series. The fertilisers were applied either in the cleared spaces along tree rows or, where ground cover was absent or sparse, in the spaces between tree rows. The sulphate of ammonia was broadcast but the placement method was used for application of rock phosphate and muriate of potash, the dosage for each tree being split up and placed in eight pockets at random points in the root zone, and then covered. Within the period under consideration each experimental area received three applications at intervals of two years.

EXPERIMENTAL RESULTS

We are concerned mainly with the effect of the post-war fertiliser treatments on growth and yield of mature trees. The data which have been analysed and are discussed in this report are those obtained up to 1953 in some, and up to 1954 in others, covering periods of six years for girth increments and four years for yield records. The six years of girth increment recording are those almost immediately following the first post-war application of fertilisers whereas the four years of yield recording correspond closely in time with the third, fourth, fifth and sixth years of girth increment recording.

In the six-treatment trials, treatments p and k are missing from the complete set of eight treatments used in the other trials. Hence main effects and interactions cannot be estimated by combining treatment means without making certain assumptions to supplement the missing information. Hitherto it has been customary to assume inter-

action effects to be zero in the six-treatment trials and thereby arrive at estimates of main effects. But evidence from other trials suggests that a more appropriate assumption is to regard effects K and PK as negligible and thereby derive estimates of the other main effects and interactions. This has been adopted in the present paper.

Treatment effects vary widely from trial to trial and some of this variation may represent real differences in the way different areas respond to treatment. However, at the risk of oversimplification, generalisation has been attempted by averaging the treatment means and effects over all the trials. To obtain such an average, equal weight has been given to each trial, although other techniques involving different methods of weighting the separate effects have been examined.

Effect of Fertilisers on Growth

N Effect — The effect of nitrogen on growth of the trees, although never very marked, became more noticeable with time. A positive effect due to nitrogen was observed in only seven trials in the first year, and of these only one was significant, whereas by the sixth year twelve trials showed positive response to nitrogen and five of these were of significant magnitude.

Averaging the results over six years, the mean N effect over the nine trials of the 2^3 NPK series is + 0.026 inches per annum and is statistically significant (see Table 2). In the five trials of the six-treatment series, the mean effect is + 0.005 inches per annum and is not significant, but the six year average effect is established with confidence in trials No 10 and 14. In the 3^3 NPK series, however, the six year mean effect is not significant in any one trial or when averaged over the three trials.

Combining the results of the 17 trials we find that the six year mean N effect is + 0.018 inches per tree per annum and is significant at the 10 per cent level. Considering each year separately, the mean effect is significant in the second and fifth years, and is highly significant in the sixth year amounting to an increase of 0.045 inches per tree.

P Effect — A beneficial effect on girth increment due to applications of phosphate was established in the fourth year of recording, and all areas by this time had received two applications of fertilisers. At this stage the P effect was positive in thirteen trials and was significant in four of them. In the following year the mean positive effect was greater and reached statistical significance in eight trials. By the sixth year the P effect in terms of girth increment was positive in 16 out of the 17 trials although considered individually, it was statistically significant in only six experiments.

Averaging the results over six years the response to P is significant in four of the nine trials of the 2^3 NPK series and is highly significant when averaged over the nine trials. The magnitude of the mean effect is estimated to be + 0.045 inches per tree per annum. The response is particularly marked in experiment No 2 on a brownish grey heavy clay loam derived from shales (Batu Anam soil series). Experiments of the six-treatment series also show similar responses, the mean P effect being significant in the fourth, fifth and sixth years of recording and also when averaged over the six years (+ 0.025 inches per tree per annum). The response is most marked in experiment No 10 where the soil is a brownish red medium loam derived from sandstone (Kedah series). In the three experiments of the 3^3 NPK series the mean effect is not significant in any one year nor when averaged over the six years.

Combining the results of the 17 trials (Table 2) we find that marked positive P effects are established in the last three years of the period considered, corresponding to the fifth, sixth and seventh years after commencement of the manuring programme. The magnitude of the mean effect on girth increment in the sixth year is + 0.061 inches

Table 2. Girth Increments

Combination of Treatment Means and Effects from 2^3NPK, Six-Treatment and 3^3NPK Series

Series	Mean girth incrt	Treatment means averaged over 6 years, inches								s.e. of a treament mean
		(1)	n	p	k	np	nk	pk	npk	
2^3NPK	0.763	0.738	0.749	0.770	0.717	0.806	0.760	0.775	0.791	±0.017
Six-Treatment	0.644	0.632	0.631	(0.651)	(0.632)	0.658	0.631	0.651	0.667	0.013
3^3NPK (omitting highest level)	0.817	0.860	0.911	0.843	0.728	0.755	0.784	0.807	0.844	0.061
Mean of 17 trials	0.738	0.728	0.742	0.748	0.694	0.754	0.726	0.744	0.764	0.014

Series		Mean girth incrt	Effects			s.e. of N, P or NP effect	Effects				s.e. of K, NK, PK or NPK effect
			N	P	NP		K	NK	PK	NPK	
2^3NPK		0.763	+0.026*	+0.045***	0.000	+0.012	−0.005	+0.003	0.000	−0.013	±0.012
Six-Treatment		0.644	+0.005	+0.025*	+0.007	0.011	(0.000)	+0.004	(0.000)	+0.004	0.013
3^3NPK (omitting highest level)		0.817	+0.014	−0.009	−0.039	0.043	−0.052	+0.033	+0.078+	+0.030	0.043
Mean of 17 trials		0.738	+0.018+	+0.030*	−0.005	0.010	−0.012	+0.009	+0.014	0.000	0.011
Annual means averaged over trials by years	First	0.848	−0.022	−0.010	−0.012	±0.016	−0.003	+0.001	+0.018	−0.015	±0.016
	Second	0.842	+0.027*	+0.014	−0.013	0.013	−0.009	−0.010	+0.002	+0.013	0.013
	Third	0.816	+0.011	+0.021	−0.013	0.017	−0.028+	0.000	+0.012	+0.002	0.017
	Fourth	0,680	+0.019	+0.038*	+0.021	0.016	−0.013	+0.020	+0.015	−0.007	0.016
	Fifth	0.688	+0.025+	+0.050***	−0.006	0.015	−0.009	+0.008	+0.016	−0.001	0.016
	Sixth	0.574	+0.045***	+0.061***	−0.008	0.012	−0.008	+0.032*	+0.020	+0.005	0.013
Mean over 6 years		0.738	+0.018+	+0.030**	−0.005	0.010	−0.012	+0.009	+0.014	0.000	0.011

Significance levels at 10, 5, 1 and 0.1% are denoted by +, *, **, ***, respectively.

Effects K and PK are assumed to be zero in the six-treatment trials and are therefore entered as such in the above table (in parentheses). Each effect can then be averaged over 17 estates. From the assumption that K = PK = 0 in the six-treatment trials, it follows that treatment k = control (1) and treatment p = pk. These estimates of the missing treatments p and k have been entered in the table (in parentheses). Each treatment mean can then be averaged over 17 estates. The mean effect (averaged over 17 estates) are then in accord with the treatment means.

per tree and is highly significant. The average effect over the six year period, also very significant, is + 0.030 inches per tree per annum.

K Effect — Experiments of the six-treatment series provide no direct evidence of a K effect since K and NK effects are confounded. In trials of the 2^3 NPK series no significant K effects are shown, while in the 3^3 NPK series also there is no convincing evidence of a response to this nutrient element. In the latter group, the average effect when averaged over the three trials is significantly negative at the 10 per cent level in the third year of recording but no significant effects are established when averaging over six years.

No response to K is shown again when combining the results of all the experiments. There was an indication of a negative effect in the third year, significant at the 10 per cent level only, but when averaged over the six years there was no significant effect. We conclude that application of potassium had no detectable beneficial effect on rate of growth of the trees.

Interaction effects — None of the interactions assumes significant values when these effects are averaged for six years over the 17 experiments (Table 2).

The N × P interaction proved to be negative in the third year in one of the trials of the 2^3 NPK series and the average effect in the 3^3 NPK series is shown to be significantly negative in the second year only, but in neither case was the effect maintained. The five trials of the six-treatment series show a significantly positive N × P interaction effect in the second year but not when averaged over six years. It would appear that interdependence of N and P, measured in terms of their effect on rate of growth, has not been important.

Although the existence of N × K interaction effect is not established on evidence derived from analysis of girth increment records obtained over a period of six years, it is interesting to note that there is evidence to suggest that such an effect may be developing. The mean effect of interaction NK for the 3^3 NPK series is significant in the fourth and sixth years and is also shown to be significantly positive in the sixth year when combined results from the 17 trials are averaged.

There is no firm evidence to suggest that interaction effects PK and NPK are important.

Summary of Effects on Girth Increments

Averaging the girth increment values over six years and over the 17 trials the only notable effects are those obtained from applications of nitrogen and phosphate. The nitrogen effect is significant at the 10 per cent level and is estimated to be worth an increase in girth of 0.018 inches per tree per annum or about 2½ per cent per annum. The phosphate effect is highly significant amounting to an increase of 0.030 inches per tree per annum or about 4 per cent per annum. The effects developed strongly in the sixth and seventh years after the first application of fertiliser as we find that the phosphate effect, measured in terms of girth increment, is highly significant in the last two years of recording (+ 0.050 and + 0.061 inches) and the nitrogen effect also is highly significant in the sixth year (+ 0.045 inches). The nitrogen effect on girth increment is generally found to be independent of the presence of potassium (compare yield responses) but the final year provides an exception because of a significant NK interaction. In the sixth year the mean nitrogen effect in the presence of potassium (i.e. N + NK) is + 0.077 inches per tree, whereas the nitrogen effect in the absence of potassium (i.e. N – NK) is only +0.013 inches per tree. Whether this difference between the effects of nitrogen in the presence and absence of potassium is maintained in later years remains to be seen. Hence for a girth increment response we establish a requirement for nitrogen and phosphate but the need for potassium is demonstrated clearly only in the last year of recording. The results are summarised in Table 2.

Effect of Fertilisers on Yield of Rubber

N Effect — The average response to nitrogen alone in the 17 trials is not established as significant in the first three years of yield recording corresponding to the period up to about five years after the first application of fertilisers. But the nitrogen effect in the fourth year of recording is positive in all except one trial and the mean effect is significant.

Considering the experiments individually, we find that four of them show a significant positive N effect in the fourth year. In the same year the mean effect of all trials in each of the two groups 2^3 NPK series and the six-treatment series is also significant. Combining the results of all 17 trials the average N response over the four years is not significant and corresponds to a mere 1 per cent average increase in yield per tapping due to application of nitrogen alone. However, in the fourth year the trial average effect is significant amounting to + 0.038 tahils per tree or 3.7 per cent increase in yield (see Table 3).

P Effect — There is evidence of an earlier effect on yield due to application of phosphate. Results for the first year of recording show significant P effect in five trials while the mean effects in the 2^3 NPK series and the six-treatment series respectively are also significant. The mean P effect for the five trials of the six-treatment series is consistently positive in each of the four years but this is almost entirely due to the very marked continuous response in trial No 10 which, over four years, gives a mean response of + 0.195 tahils per tree per tapping or about 12 per cent increase. By the fourth year the P effect is positive in eleven out of 17 trials.

Combining the results of the seventeen trials (Table 3) we find that the average response to P is + 0.020 tahils per tree per tapping and is significant, and so too are the responses in the first and third years of recording.

K Effect — The results show no indication of a beneficial effect due to application of potassium alone. Examining the data showing the K effect in individual trials in different years, and their means, we find that the number of negative effects is, in fact, greater than the number of positive effects but statistical significance is only achieved in isolated instances and are not consistent. We conclude therefore that applications of potassium alone have had no noticeable effect on yield of rubber.

Interaction NP — Although NP interaction effect is established as significantly positive at different times in three experiments and fairly consistently in one of them (No 9), we find that the mean effects in different years and over the four years, either for each of the three groups separately or for all experiments, are not statistically significant. It would appear from the results of these 17 experiments that the interdependence of N and P in their effects on yield of rubber is not generally important.

Interaction NK — There is some evidence to indicate that NK interaction effect, measured in terms of yield may be a real effect. Significantly positive effects are observed in three experiments in the first year of recording, two in the second year, three in the third year and one in the fourth year. The mean effect of the nine trials in the 2^3 NPK series is significant in the first and second years, and so is the mean effect over the four years. The average for the five trials of the six-treatment series is positive in each year but only in the second year is significance established and we find all five trials giving positive values. The interaction is most noticeable in trial No 10. Trial No 15 (in the 3^3 NPK series) gives large positive values throughout and, when averaged over the four years, the magnitude of the effect amounts to + 0238 tahils per tree per annum, statistically significant despite a large standard error.

Table 3. Yields

Combination of Treatment Means and Effects from 2^3NPK, Six-Treatment and 3^3 NPK Series

Series	Mean yields	Treatment means averaged over 4 years, tahils per tree per tapping								s.e. of a treatment mean
		(1)	n	p	k	np	nk	pk	npk	
2^3NPK	1.075	1.081	1.070	1.086	1.046	1.074	1.071	1.069	1.099	±0.013
Six-Treatment	1.048	1.022	1.031	(1.059)	(1.022)	1.061	1.038	1.059	1.091	0.013
3^3NPK (omitting highest level)	0.973	1.009	0.971	1.017	0.901	0.957	1.001	0.948	0.978	0.067
Mean of 17 trials	1.049	1.051	1.041	1.066	1.013	1.049	1.049	1.044	1.075	0.015

Series	Mean yields	Effects			s.e. of N, P or NP effect	Effects				s.e. of K NK, PK or NPK effect
		N	P	NP		K	NK	PK	NPK	
2^3NPK	1.075	+0.008	+0.015	−0.001	±0.009	−0.007	+0.020*	+0.011	+0.002	±0.009
Six-Treatment	1.048	+0.015	+0.040***	−0.002	0.011	(0.000)	+0.019	(0.000)	+0.011	0.013
3^3NPK (omitting highest level)	0.973	+0.008	+0.004	−0.023	0.047	−0.032	+0.057	+0.008	−0.012	0.047
Mean of 17 trials	1.049	+0.010	+0.020*	−0.003	0.010	−0.009	+0.026*	+0.007	+0.002	0.010
Annual means averaged over trials by years First	0.979	−0.002	+0.022*	+0.004	±0.009	−0.005	+0.015	+0.003	+0.005	±0.010
Second	1.051	−0.012	+0.012	+0.003	0.013	−0.006	+0.034**	+0.004	−0.001	0.013
Third	1.124	+0.015	+0.026+	−0.009	0.014	−0.014	+0.025+	+0.006	+0.001	0.014
Fourth	1.041	+0.038*	+0.020	−0.009	0.015	−0.011	+0.029+	+0.014	+0.003	0.015
Mean over 4 years	1.049	+0.010	+0.020*	−0.003	0.010	−0.009	+0.026*	+0.007	+0.002	0.010

The footnotes below Table 2 also apply above.

Combining the results of 17 experiments (Table 3) we find that the average effect over four years, amounting to + 0.026 tahils per tree per tapping, is significant; the effect is highly significant in the second year of recording and is significant at the 10 per cent level in the third and fourth years. We conclude, therefore, that the interdependence of N and K effects on yield of rubber may be important. There is an indication that NK interaction effect is more marked in replantings than in new plantings.

Interaction PK — Only one trial (No 9) shows a significant positive effect, and then only in two years, while a significant negative effect is observed in most years in another trial (No 17). The average effects for each of the three series are not significant, and when combining the results of the 17 experiments (Table 3) we find that the mean PK interaction effect is not significant in any one year or when averaged over the four years. We conclude therefore that the effect of applications of one of these nutrient elements (P or K) on yield is independent of the presence or the absence of the other.

Interaction NPK — The NPK effect is confounded with sub-block differences in some of the trials and when we examine the data we find a few significant NPK interaction effects in individual trials but these are not consistent. Combining the results of the 17 trials we find the mean effect negligible.

Summary of Effects on Yield

The estimate of the effect of fertilisers on yield is based on analysis of records obtained over only four years corresponding with the period from about two to six years after the first post-war application of fertilisers. The only notable effects in this short period are a significant P effect and a significant NK interaction amounting to + 0.020 and + 0.026 tahils per tree per tapping respectively (Table 3). The mean effect due to nitrogen, estimated as + 0.010 tahils per tree per tapping, is not significant but the nitrogen effect in the presence of potassium (i.e. N + NK) is + 0.036 and is significant, whereas the nitrogen effect in the absence of potassium (i.e. N – NK) is – 0.016 and is not significant. Interaction of nitrogen with phosphate is not established.

Judged on the average results of all the 17 trials it would appear that the most effective treatment is one which provided for applications of nitrogen, phosphorus and potassium. The mean percentage response to phosphate, over the four years, is about 2 per cent per annum and with nitrogen in the presence of potassium it is about 3½ per cent increase in yield. We also note that significant mean nitrogen effect is found in the fourth year of recording, but again it is associated with an NK interaction. In this last year of recording the mean response to phosphate is about 2 per cent, and with nitrogen in the presence of potassium the response in terms of increased yield averages about 6 per cent.

COMPARISON OF EFFECTS INLAND SOILS AND COASTAL ALLUVIAL SOILS

The variability between trials on any one soil type is large and consequently differences between responses on inland residual soils and those on coastal alluvial soils have to be very marked before their significance can be confidently established with the number of trials considered in this report. Further, in making comparisons there is some risk that other factors may be confounded; we cannot claim that the twelve trials on inland soils on the one hand and the five trials on coastal soils on the other are identical in all respects except for the soil type (group type) on which they are located.

When we compare mean responses in the two groups in terms of girth increments averaged over six years we find that no significant differences are established but the results obtained do give some indications that real differences do exist. When we

consider each of the two groups of experiments separately (Table 4) we find that the average nitrogen response in terms of girth increments, although not significant, is similar in magnitude on both groups of soils. Mean response to phosphate, however, is highly significant in the trials on inland soils (+ 0.039 inches per tree per annum) and is negligible on coastal alluvial soils (+ 0.008 inches per tree per annum); the difference between the two values, although not statistically significant, is in accord with that observed in terms of yield response. The NK interaction effect on girth increments is not marked on either inland or coastal soils. The interaction PK is negligible in the inland trials but reaches significance in the coastal (+ 0.070 inches per tree per annum), although due largely to a marked contribution from one trial.

With regard to effects on yields, we note that the mean yield response to nitrogen, when averaged over the four years of recording, is + 0.033 tahils per tree per tapping on coastal soils whereas the mean response for the group of experiments on inland soils is zero; the difference between the two values is significant but only at the 10 per cent level. No other differences are significant but we might refer also to P effects and NK interactions (Table 4) since these were significant when averaged over all trials. The mean yield response to phosphate is highly significant for the trials on inland soils (+ 0.028) and is negligible for those on coastal alluvial soils (+ 0.001 tahils per tree per annum). The interaction NK is positive on both groups of soils although statistical significance is achieved only for the inland group.

We deduce that the main differences between responses on inland residual soils and on coastal alluvial soils are that there is little or no effect due to phosphate on the latter whereas a marked phosphate effect is established on inland soils. The yield response to nitrogen on inland soils is marked only in the presence of potassium. On coastal alluvial soils, however, the picture is not quite so clear; there is some indication of a response to nitrogen alone, although here also the effect may be enhanced if fertiliser treatment provides for applications of both nitrogen and potassium.

Influence of Pre-War Fertiliser Treatments on Post-War Girth Increments and Yield

As stated earlier, the experiments described were started originally in the period 1935 to 1938 at time of planting. The pre-war manuring programme consisted of fertiliser treatments at planting and during the first few years of growth up to the end of 1941. The total amounts applied varied from trial to trial depending on how long before 1941 the area was planted. Trial No 3 is an exception in that the area had reached maturity at the time of the pre-war applications, and the dosages of fertilisers applied were correspondingly larger, but in all other trials the total amounts did not exceed 9.4, 9.2 and 11.1 oz (unit levels only) of N, P_2O_5 and K_2O respectively. These were the amounts applied in experiment No 10 which started in 1935. All others started later and the number of dressings applied was correspondingly lower.

The post-war manuring programmes started some 9, 10 or 11 years after planting (except trial No 3 where the trees were then 20 years old). The treatment in each plot was the same as in the pre-war programme (except Nos 4 and 5 as noted earlier) although the amounts applied were greater and constant for all trials.

We have examined in detail the girth increments over the six year period immediately following the start of post-war manuring and we have also analysed the yield records during the last four years of this period. Yield recording did not begin until about two years after the commencement of post-war manuring, although unrecorded tapping had been in operation prior to the post-war manuring.

Table 4. Comparison of Inland and Coastal Soils

A *Effects on girth increments, inches per tree per annum averaged over six years*

Effect	Inland (12 estates)					Coastal (5 estates)					Difference between mean effects Inland-Coastal	s.e. of difference
	Number of effects	Mean effect	s.e.	min	Range max	diff	Number of effects	Mean effect	s.e.	min	Range max	diff		
N	12	+0.016	±0.010	−0.027	+0.076	0.103	5	+0.022	±0.026	−0.031	+0.077	0.108	−0.006	±0.023
P	12	+0.039***	0.010	−0.027	+0.158	0.185	5	+0.008	0.026	−0.036	+0.047	0.083	+0.031	0.023
K	8	−0.002	0.014	−0.028	+0.032	0.060	4	−0.045	0.032	−0.144	+0.007	0.151	+0.043	0.037
NP	12	−0.004	0.010	−0.068	+0.039	0.107	5	−0.009	0.026	−0.052	+0.015	0.067	+0.005	0.016
NK	12	+0.013	0.010	−0.022	+0.049	0.071	5	0.000	0.026	−0.032	+0.094	0.126	+0.013	0.025
PK	8	−0.006	0.014	−0.067	+0.033	0.100	4	+0.070*	0.032	−0.003	+0.167	0.170	−0.076	0.043
NPK	12	−0.012	0.010	−0.049	+0.022	0.071	5	+0.027	0.026	−0.039	+0.152	0.191	−0.039	0.037
Mean girth increments	12	0.750		0.386	1.071	0.685	5	0.709		0.467	0.936	0.469	+0.041	0.109

B *Effects on yield, tahils per tree per tapping averaged over four years*

Effect	Inland (12 estates)					Coastal (5 estates)					Difference between mean effects Inland-Coastal	s.e. of difference
	Number of effects	Mean effect	s.e.	min	Range max	diff	Number of effects	Mean effect	s.e.	min	Range max	diff		
N	12	+0.000	±0.008	−0.108	+0.043	0.151	5	+0.033	±0.028	0.000	+0.073	0.073	−0.033+	±0.019
P	12	+0.028***	0.008	−0.032	+0.195	0.227	5	+0.001	0.028	−0.026	+0.029	0.055	+0.027	0.023
K	8	−0.005	0.011	−0.040	+0.032	0.072	4	−0.028	0.035	−0.061	+0.006	0.067	+0.023	0.019
NP	12	+0.008	0.008	−0.022	+0.047	0.069	5	−0.028	0.028	−0.118	+0.048	0.166	+0.036	0.032
NK	12	+0.019*	0.009	−0.036	+0.071	0.107	5	+0.041	0.028	−0.031	+0.238	0.269	−0.022	0.052
PK	8	+0.011	0.011	−0.032	+0.074	0.106	4	+0.007	0.035	−0.060	+0.065	0.125	+0.004	0.033
NPK	12	+0.005	0.009	−0.063	+0.034	0.097	5	−0.004	0.028	−0.056	+0.052	0.108	+0.009	0.023
Mean yields	12	1.078		0.785	1.572	0.787	5	0.981		0.635	1.322	0.687	+0.097	0.149

Significance levels at 10, 5, 1 and 0.1% are denoted by +, *, **, ***, respectively.
Only 8 of the 12 inland trials and 4 of the 5 coastal trials provide estimates of effects K and PK.
The standard error of mean effects is calculated by pooling the errors obtained in the individual trials.
The standard error of the difference between inland and coastal mean effects is derived from inter-estate variability estimated by the respective ranges.

TABLE 5. EFFECTS ON INITIAL AND FINAL GIRTH MEASUREMENTS COMBINATION OF 2^3NPK, SIX-TREATMENT AND 3^3NPK SERIES

A *Initial girths, inches per tree*

Series	Mean girth measurements	Treatment means							
		(1)	n	p	k	np	nk	pk	npk
2^3NPK	24.74	24.25	24.68	25.05	24.18	25.10	24.20	25.10	25.37
Six-Treatment	25.24	24.65	24.63	(24.65)	(25.55)	26.09	24.75	25.55	26.03
3^3 (omitting highest levels)	24.64	24.43	24.40	24.35	23.83	25.98	24.09	25.11	24.94
Mean of 17 trials	24.87	24.40	24.62	24.81	24.52	25.55	24.34	25.23	25.49

Series	Mean girth measurements	Effects						
		N	P	NP	K	NK	PK	NPK
2^3 NPK	24.74	+ 0.193	+ 0.831	− 0.032	− 0.057	− 0.047	+ 0.217	+ 0.161
Six-Treatment	25.24	+ 0.276	+ 1.133	+ 0.235	(0.000)	+ 0.028	(0.000)	− 0.094
3^3 (omitting highest level)	24.64	+ 0.421	+ 0.907	+ 0.306	− 0.299	− 0.377	+ 0.156	− 0.526
Mean of 17 trials	24.87	+ 0.258	+ 0.933	+ 0.106	− 0.083	− 0.083	+ 0.143	− 0.035

B *Final girths, inches per tree*

Series	Mean girth measurements	Treatment means							
		(1)	n	p	k	np	nk	pk	npk
2^3 NPK	29.27	28.65	29.12	29.66	28.50	29.64	28.72	29.81	30.08
Six-Treatment	29.00	28.32	28.26	(28.32)	(29.35)	29.94	28.53	29.35	29.97
3^3 (omitting higest level)	29.56	29.38	30.07	29.58	28.21	30.44	28.97	29.73	30.06
Mean of 17 trials	29.24	28.68	29.03	29.25	28.70	29.87	28.71	29.66	30.05

Series	Mean girth measurements	Effects						
		N	P	NP	K	NK	PK	NPK
2^3 NPK	29.27	+ 0.233	+ 1.051	− 0.109	+ 0.011	+ 0.008	+ 0.285	+ 0.135
Six-Treatment	29.00	+ 0.342	+ 1.292	+ 0.266	(0.000)	+ 0.154	(0.000)	− 0.118
3^3 (omitting highest level)	29.56	+ 0.663	+ 0.799	− 0.066	− 0.624	− 0.116	+ 0.511	− 0.151
Mean of 17 trials	29.24	+ 0.341	+ 1.077	+ 0.009	− 0.105	+ 0.029	+ 0.241	+ 0.010

Effects K and PK are assumed to be zero in the six-treatment trials and are therefore entered as such in the above table (in parentheses). Each effect can then be averaged over 17 estates.

Table 6. Percentage Phosphate Effect

	Trial number	Initial girth	Final girth	Yield					Girth increment						
				First year	Second year	Third year	Fourth year	1-4 years	First year	Second year	Third year	Fourth year	Fifth year	Sixth year	1-6 years
2^3 NPK Series	1	− 0.5	− 1.0	− 3.6	− 1.2	− 3.1	− 2.7	− 2.7	+ 3.7	+ 2.9	− 4.4	+ 3.5	−14.6	+ 1.5	− 1.4
	2	+ 9.3	+11.3	+ 6.6	+ 2.1	+ 2.3	− 1.2	+ 2.2	− 0.3	+ 8.3	+23.1	+31.3	+56.4	+69.2	+25.3
	3	+ 0.2	− 0.5	− 3.3	− 1.5	− 6.1	+ 5.2	− 2.0	− 7.8	− 9.8	−10.0	− 0.2	− 4.6	−13.1	− 7.7
	4	+ 0.7	+ 0.5	+ 1.6	+ 3.1	+ 3.8	+ 4.6	+ 3.4	+ 0.9	+ 5.8	+ 0.3	− 2.3	+26.1	+ 6.6	+ 6.1
	5	− 0.3	+ 1.5	− 0.3	− 0.2	+ 0.6	+ 0.5	+ 0.1	+ 7.8	+ 5.4	+ 7.3	+12.3	+20.0	+ 9.5	+10.3
	6	+ 5.6	+ 6.1	+ 8.2	+ 3.6	+ 3.4	+ 0.8	+ 3.7	+14.6	− 0.8	+ 5.6	+16.0	+10.6	+13.7	+ 9.0
	7	+ 7.2	+ 5.8	+ 3.4	0.0	− 0.6	+ 2.5	+ 1.1	− 3.2	+ 1.2	− 5.2	+ 0.1	+ 5.4	+ 6.4	+ 0.6
	8	+ 4.5	+ 4.0	+ 4.5	+ 4.2	+ 6.7	+ 6.2	+ 5.5	− 5.4	− 0.1	− 2.6	+ 1.8	+24.5	+ 9.8	+ 2.0
	9	+ 5.8	+ 6.5	+ 6.3	+ 1.6	+ 6.1	+ 3.8	+ 4.3	—	+ 9.2	+13.5	+ 3.6	+12.0	+24.9	+ 9.3
Six-Treatment Series	10	+ 6.1	+ 6.4	+10.4	+11.7	+13.0	+15.2	+12.4	—	− 0.2	−14.0	+13.4	+13.6	+19.6	+11.8
	11	+ 0.5	+ 1.0	− 3.3	− 4.3	− 0.1	+ 0.6	− 1.8	+ 0.8	+ 2.3	+ 2.9	+ 4.4	+ 7.0	+ 5.7	+ 3.9
	12	+ 8.9	+ 8.6	+ 2.9	+ 3.8	+ 5.9	− 0.3	+ 3.1	− 9.5	− 7.6	+ 2.0	+10.1	+14.5	+15.0	+ 2.9
	13	+ 4.3	+ 4.0	− 1.1	− 1.3	− 4.5	− 0.2	− 1.8	+ 2.2	− 0.4	− 0.8	+ 8.5	+ 1.9	+ 7.8	+ 3.0
	14	+ 2.8	+ 2.3	+ 2.4	+ 0.4	+ 2.2	− 0.7	+ 1.1	− 3.8	+ 0.5	− 2.2	+ 7.2	− 4.6	+ 2.8	0.0
3^3 NPK Series	15	+ 4.0	+ 3.6	− 0.7	− 3.0	+ 4.7	+ 0.1	+ 0.5	− 2.9	+10.4	+12.6	− 2.0	−22.7	+ 8.2	+ 0.2
	16	+ 7.1	+ 4.8	+ 2.4	0.0	− 2.0	− 1.8	− 0.3	− 4.4	− 3.1	−13.0	+ 0.5	+ 2.7	+ 1.0	− 3.2
	17	− 0.3	− 0.5	+ 2.4	− 3.0	+ 5.9	+ 2.1	+ 1.6	− 3.1	+ 2.2	+ 5.0	− 9.3	− 7.7	+15.0	− 0.3
Unwtd mean of 17 estates		+ 3.9	+ 3.8	+ 2.3	+ 0.9	+ 2.2	+ 2.0	+ 1.8	− 0.7	+ 1.5	+ 1.2	+ 5.8	+ 8.3	+12.0	+ 4.2
Correlation coefficient with initial girth			+ 0.95***	+0.66**	+0.48*	+0.30 NS	+0.03 NS	+0.42 +	−0.21 NS	−0.06 NS	+0.15 NS	+0.51*	+0.43 +	+0.55*	+0.41 +

Significance levels at 10, 5, 1 and 0.1% are denoted by +, *, **, ***, respectively, and are quoted only for correlation coefficients.

The mean percentage girth increment response in the first year is averaged over 15 trials only. For trial 10 data were not available, and in trial 9 a change in the height at which girths were measured has lead to a gross overestimate of the percentage response in the first year.

Table 7. Percentage Nitrogen Effect in the Absence of Potassium

	Trial number	Initial girth	Final girth	Yield					Girth increment						
				First year	Second year	Third year	Fourth year	1-4 years	First year	Second year	Third year	Fourth year	Fifth year	Sixth year	1-6 years
2^3 NPK Series	1	− 0.4	− 1.5	− 0.8	+ 0.3	− 8.3	+ 3.5	− 3.2	− 4.8	−12.9	− 8.6	+17.5	−10.0	+ 8.2	− 1.6
	2	+ 1.3	+ 3.4	− 5.0	− 4.0	− 0.1	+ 9.2	+ 0.8	−12.9	+ 4.5	+14.0	+19.2	+14.3	+37.6	+ 9.6
	3	− 1.4	− 2.1	− 5.6	− 0.6	+ 8.3	− 1.9	+ 0.5	+ 1.4	+41.5	+17.6	+17.3	−24.6	+ 0.7	+10.3
	4	+ 1.6	+ 2.0	− 3.7	− 0.1	+ 3.1	+ 5.6	+ 1.8	+ 3.0	+20.3	+12.0	+13.9	+19.7	+ 9.8	+12.8
	5	+ 3.7	+ 4.2	− 3.1	− 1.4	− 0.1	+ 2.2	− 0.4	+14.6	+ 6.5	+ 8.2	+18.4	+12.1	− 1.0	+10.7
	6	+ 1.1	+ 0.3	− 6.0	− 2.7	+ 0.4	+ 1.3	− 1.4	− 0.4	+ 3.6	− 5.9	+ 4.4	+ 7.3	+ 2.5	+ 1.6
	7	+ 6.6	+ 3.8	− 7.5	− 7.3	− 4.2	+ 4.0	− 3.5	−16.6	− 2.5	−23.4	− 7.5	+ 1.1	+14.2	− 5.9
	8	+ 0.2	− 0.5	+ 1.4	− 0.1	+ 1.8	+ 0.5	+ 0.8	− 2.9	− 4.8	−10.9	− 4.8	+ 2.6	+ 4.8	− 3.5
	9	− 1.9	− 1.7	− 2.6	−12.6	− 5.5	− 3.4	− 6.2	—	− 6.6	− 7.4	+15.2	+ 1.0	+ 1.4	− 1.0
Six-Treatment Series	10	+ 1.3	+ 1.0	+ 0.8	− 4.6	− 0.3	+ 0.2	− 1.1	—	+ 1.5	− 4.5	− 3.8	− 6.3	+ 0.6	− 2.6
	11	+ 0.4	+ 0.0	+ 0.6	− 1.8	+ 3.2	+ 3.1	+ 1.4	+ 3.1	+ 1.3	+ 8.2	+ 4.4	− 6.8	− 4.0	+ 1.2
	12	+ 1.8	+ 0.8	+ 3.8	− 4.9	− 7.3	− 0.4	− 2.4	− 3.3	− 7.8	+ 1.7	− 3.4	+12.4	−16.3	− 1.4
	13	+ 2.5	+ 2.1	− 1.6	− 0.9	+ 2.7	0.0	+ 0.1	−19.0	− 3.0	+ 7.9	+14.8	+ 8.7	+ 9.1	+ 0.5
	14	− 1.2	− 0.7	− 0.5	− 0.5	+ 1.0	+ 1.9	+ 0.5	−20.4	+ 2.6	− 3.1	+19.6	+ 1.6	+22.9	+ 2.7
3^3 NPK Series	15	+ 2.0	+ 3.6	+ 0.3	−28.4	−13.4	− 6.2	−12.7	+25.2	+30.8	−13.2	−43.2	− 3.1	−19.5	− 1.8
	16	+ 7.4	+ 5.6	− 2.0	− 7.0	−12.1	− 8.2	− 7.3	+12.0	+ 6.9	− 3.5	−20.7	+ 5.6	−10.8	− 1.8
	17	+ 0.2	− 1.6	+ 2.9	+10.4	+22.9	+18.4	+14.2	−20.2	− 6.2	+48.2	−32.2	−12.1	−31.2	− 3.7
Unwtd mean of 17 estates		+ 1.5	+ 1.1	− 1.7	− 3.9	− 0.5	+ 1.3	− 1.1	− 2.7	+ 4.5	+ 2.2	+ 1.7	+ 1.4	+ 1.7	+ 1.5
Correlation coefficient with initial girth			+0.88***	−0.25 NS	−0.20 NS	−0.37 NS	−0.15 NS	−0.30 NS	+0.22 NS	−0.03 NS	−0.27 NS	−0.35 NS	+0.40 NS	−0.07 NS	−0.18 NS

The footnotes below Table 6 also apply above.

TABLE 8. PERCENTAGE NITROGEN EFFECT IN THE PRESENCE OF POTASSIUM

	Trial number	Initial girth	Final girth	Yield					Girth increment						
				First year	Second year	Third year	Fourth year	1-4 years	First year	Second year	Third year	Fourth year	Fifth year	Sixth year	1-6 years
2^3NPK Series	1	+ 0.3	+ 0.4	+ 5.2	+11.3	+ 5.6	+13.4	+ 8.7	+ 8.0	– 0.5	+ 4.8	–10.1	+ 5.8	–12.6	– 0.4
	2	+ 0.3	+ 1.1	– 1.7	– 5.3	+ 0.7	+ 4.9	+ 0.2	–10.3	– 3.6	+11.1	+ 5.7	+26.1	+25.6	+ 5.8
	3	– 0.4	– 2.5	+10.6	+ 2.2	– 4.0	+ 7.6	+ 3.8	– 4.8	+ 0.4	+ 6.7	+ 8.5	–10.9	– 8.5	– 1.7
	4	+ 0.5	+ 1.6	– 2.6	– 2.1	+ 1.5	– 0.7	– 0.8	– 3.0	+16.1	+ 2.4	+ 3.4	– 5.2	+17.9	+ 4.4
	5	– 0.5	+ 0.9	+ 3.5	+ 2.1	+ 2.5	– 0.8	+ 1.7	+ 6.3	+ 6.9	+ 7.3	+ 3.4	+ 9.8	– 1.7	+ 5.9
	6	+ 1.1	+ 0.8	– 2.1	– 0.5	– 3.6	+ 3.4	– 0.5	+ 3.3	+ 2.9	– 4.3	+15.1	– 2.8	+15.0	+ 4.1
	7	– 0.7	+ 0.4	–10.6	– 2.1	– 0.7	+ 2.7	– 2.4	– 4.0	– 6.6	+ 4.6	+ 3.0	+15.4	+20.1	+ 3.3
	8	+ 2.8	+ 2.9	+ 2.7	+ 0.1	+ 6.0	+ 3.8	+ 3.2	– 6.5	+ 1.2	+ 5.6	+13.4	+ 0.2	+21.8	+ 3.9
	9	+ 2.3	+ 3.1	+ 9.6	+12.2	+ 6.0	+ 4.9	+ 8.7	—	+ 2.3	+ 5.9	+17.6	+22.6	+27.7	+10.9
Six-Treatment Series	10	+ 2.7	+ 3.5	+ 4.0	+ 9.8	+ 5.4	+ 7.3	+ 6.6	—	+31.0	+ 6.6	+ 2.5	+16.4	+ 5.4	+12.8
	11	– 2.2	– 2.4	– 1.6	– 1.1	+ 0.1	– 2.9	– 1.4	+ 7.3	– 4.6	–12.7	– 2.2	+ 2.0	–22.2	– 7.5
	12	+ 1.4	+ 3.2	– 1.8	– 2.7	– 1.2	+ 1.9	– 0.9	– 6.4	– 6.3	– 5.9	+11.6	–26.5	+18.7	– 5.4
	13	+ 1.6	+ 2.0	+ 1.6	+ 6.0	+ 6.0	+ 1.8	+ 3.9	–10.4	+ 7.2	+ 5.9	–18.2	–20.1	+ 9.5	+ 2.0
	14	+ 2.4	+ 2.3	+ 1.6	+ 3.8	+ 3.6	+ 6.6	+ 3.9	–15.0	– 6.1	+15.4	+25.3	+13.7	+47.6	+11.0
3^3NPK Series	15	+ 1.3	+ 5.5	+18.2	+ 4.8	–25.6	+45.4	+23.9	+27.4	–14.2	+ 2.0	+23.0	+17.8	+37.7	+18.3
	16	– 0.2	+ 1.2	–23.9	–21.2	– 6.0	– 7.8	–14.7	–11.6	– 6.9	– 4.5	– 3.5	– 6.1	+64.0	+ 0.8
	17	– 0.6	– 1.5	– 4.5	+ 8.7	+ 7.6	+ 3.5	+ 4.4	–11.6	+ 1.8	–12.2	–10.0	– 1.9	+10.4	– 5.4
Unwtd mean of 17 estates		+ 0.7	+ 1.3	+ 0.5	+ 1.5	+ 3.2	+ 5.6	+ 2.8	– 2.1	+ 2.9	+ 2.3	+ 5.2	+ 5.7	+16.3	+ 3.7
Correlation coefficient with initial girth			*** +0.78	NS +0.35	NS +0.33	NS +0.32	NS +0.25	NS +0.36	NS –0.17	NS +0.38	+0.50*	+0.45	NS +0.21	NS +0.40	+0.60*

The footnotes below Table 6 also apply above.

Thus the present yield and girth increment data, discussed in the earlier sections of this report, are measures of the effect of post-war manuring when the trees were mature and in production, and in this we are mainly interested. But this effect may also have been influenced by the earlier pre-war fertiliser applications.

An estimation of the contribution from the pre-war manuring is handicapped by the absence of yield records preceding the post-war manuring programme, but girth records taken at the start of the post-war manuring are available and constitute the most up to date means of measuring effects which can be attributed solely to the pre-war manuring. Table 5 summarises the treatment means and effects on these 'initial' girths by listing the averages for the 2^3 NPK, six-treatment and the 3^3 NPK series of experiments, and the average over the seventeen trials. A detailed account of girths recorded about this time has previously been reported (Akhurst & Owen 1950, Fairfield Smith 1950) for some twentythree trials which include most of the present seventeen.

The main girth response, measured by comparison of 'initial' girths, is a significant positive effect due to phosphate which averages + 0.93 inches per tree or 3.9 per cent (Table 5). The effect is demonstrated in each group of trials and only three of the 17 trials fail to show a positive phosphate response. The next largest response is to nitrogen; the effect averages only + 0.26 inches per tree (or about 1.0 per cent) and is not significant. Other effects on initial girths are negligible.

A similar mean response pattern is shown by the 'final' girths recorded six years later (Table 5). Again the main response is to phosphate and averages a significant + 1.08 inches per tree (or 3.8 per cent), whereas the average nitrogen effect is only + 0.34 inches per tree (or 1.2 per cent).

Summarising the evidence compiled so far we find therefore, that effects due to fertiliser applications are discernible on 'initial' girths, yields, girth increments and 'final' girths. The data in Tables 6, 7 and 8 have been assembled with a view to relating the effects of fertilisers on yield, girth increment and final girths (which could be due to either the pre-war or post-war manuring or both) to the effects on initial girth, which are clearly due entirely to the earlier pre-war applications. In these tables the effects are all resummarised and the responses in each trial have been expressed as percentages of the mean for the same trial, i.e. mean initial girth, mean yield, mean girth increment or mean final girth. For example the girth increment response to phosphate in trial No 1 in the first year of recording was + 0.028 inches and the mean girth increment in that experimental area the same year was 0.75 inches; the corresponding percentage effect is therefore given in Table 6 as + 3.7 per cent.

As the chief responses which have been established in terms of one or the other of these four measures (initial girth, final girth, yield and girth increment) are due to phosphate, nitrogen and the interaction NK, only these effects are now considered. Table 6 deals solely with the percentage phosphate effects, but the nitrogen effect and the NK interaction effect have been combined to give, in Table 7, the percentage nitrogen effect in the absence of potassium (i.e. N – NK), and in Table 8, the percentage nitrogen effect in the presence of potassium (i.e N + NK).

Phosphate effects — The mean percentage effect of phosphate on initial girth is a significant + 3.9 per cent. This is an effect due to pre-war manuring.

The mean percentage phosphate effect on yield obtained after commencement of the post-war manuring programme is significant in the first year of yield recording (+ 2.3 per cent), nearly so in the third year (+ 2.2 per cent), and averages a significant + 1.8 per cent over the four year period. The correlation coefficient relating the percentage effects on yields of the 17 trials in different years with the corresponding effects on the initial girths is very significant (+ 0.66) in the first year and is again significant, al-

though smaller, in the second year of recording. Thereafter the correlation declines and the coefficient is negligible in the fourth year, despite the fact that the mean percentage yield response to phosphate is maintained at about + 2 per cent throughout most of the four year period. It is not certain how much of this response can be attributed to pre-war phosphate manuring, but it is evident that post-war phosphate applications have had an effect, otherwise the maintenance of the yield response to phosphate in the latter years, coupled with their lack of correlation with initial girth responses, cannot readily be explained. Further, pre-war phosphate manuring is known to have been effective — at least in terms of initial girths, and the correlation of these girth responses with the yield responses two and three years later suggests either an effect on yield which can be traced directly to pre-war phosphate manuring or that yield responses to post-war phosphate applications have tended to occur earliest in those trials where girth response to pre-war phosphate treatment was greatest.

In regard to girth increment, the annual mean percentage responses (Table 6) are negligible in the first three years of recording, but thereafter increase markedly until the final year when the average response to phosphate is + 12 per cent and is highly significant. Similarly the correlation of these girth increment responses with those of initial girth is found to be non-significant in each of the first three years and significant in the last three years. This build up of girth increment response to phosphate in the later years strongly suggests effects due mainly to the post-war applications of phosphate. The fact that these responses in the last three years are significantly correlated with the effects on initial girths is probably a further demonstration that trials showing a response to the pre-war phosphate treatment, measured in terms of initial girths, have also tended to show girth increment response to post-war applications of phosphate. It seems unlikely that these effects on girth in the post-war period can be traced directly to pre-war phosphate treatment since significant correlation would then be expected with the earlier years of girth increment observation.

Similar conclusions are arrived at when we examine the correlation between initial girths and final girths (Table 6). The mean response to phosphate in final girths is a significant + 1.08 inches per tree or + 3.8 per cent. This compares with an effect amounting to + 0.93 inches per tree or + 3.9 per cent obtained in the initial girths six years earlier. The highly significant correlation observed between initial and final girth responses is not surprising. But the fact that the percentage response to phosphate has been very nearly maintained from initial to final girths, and the absolute value of the mean effect has increased from + 0.93 to + 1.08 inches per tree, is a further indication of effect due to post-war applications of phosphate.

Nitrogen effects in the absence of potassium — When measured in terms of initial girths, the mean response to pre-war nitrogen, applied in the absence of potassium, averages only + 1.5 per cent (Table 7). Considering effects in the period following the recording of initial girths we find that the mean effect on yield due to nitrogen in the absence of potassium is not significant except in the second year (– 3.9 per cent). The average effect over the four years of yield recording is only – 1.1 per cent and is also not significant. Similarly there is little evidence of response in terms of girth increment, the only exception being in the second year (+ 4.5 per cent). None of the correlations of yield or girth increment responses with effects on initial girth is significant. Finally, the mean response measured in terms of final girths is merely + 1.1 per cent and is less than the response observed in initial girths We conclude that there has been very little response to the post-war manuring with nitrogen in absence of potassium.

Nitrogen effects in the presence of potassium — Examination of initial girths showed no response to pre-war applications of nitrogen in the presence of potassium, the estimated effect being a negligible + 0.7 per cent. Post-war applications of nitrogen in the

presence of potassium, however, have had a beneficial effect on yield. The mean percentage response (Table 8) is significant in the last two years of recording and when averaged over the four year period. The magnitude of the effect increases steadily from + 0.5 per cent in the first year to + 5.6 per cent in the fourth year, but the correlation coefficient relating the percentage effects on yields of the 17 trials in different years with the corresponding effects on the initial girths is not significant. This response build up, and the absence of correlation with initial girth responses, suggests that the observed effects are attributable to post-war, rather than pre-war, applications of nitrogen with potassium.

A similar development is demonstrated by the percentage girth increment responses (Table 8). Mean response is negligible in each of the first three years of girth recording but reaches a highly significant + 16.3 per cent in the final year. In terms of final girths the mean response to nitrogen with potassium averages only + 1.3 per cent, but is almost double that observed for initial girths. Moreover, 14 of the 17 trials show positive response to this treatment. Hence there is further indication, consistent with the late development of girth increment response, that post-war applications of nitrogen in the presence of potassium have had a beneficial effect on growth.

We have examined the possibility that some of the effects measured by the data presented may not have been entirely due to fertiliser treatment given in the post-war period, when the trees were in production, but may have been influenced to some extent by the earlier pre-war treatments applied when the trees were very young. Summarising the evidence discussed above we find that girths measured before the commencement of the post-war manuring programme (initial girths) show no marked effect due to pre-war treatment with nitrogen whether applied in the presence or absence of potassium, but a clear response to the pre-war applications of phosphate is demonstrated.

Post-war applications of nitrogen in the absence of potassium has also had no detectable effect, but post-war nitrogen applied in the presence of potassium has latterly had beneficial effects on yield and girth increment. Phosphate applied during maturity probably benefitted yields and had an increasingly beneficial effect on growth.

DISCUSSION AND CONCLUSIONS

Before attempting to assess the advantages of manuring of mature rubber based on results presented in this report there are certain relevant factors which should be taken into consideration. In the first place, the trees in all experiments described were healthy and vigorous when the manuring programme started after the war. In twelve of the trials the trees were growing on virgin soil opened up from jungle a little over ten years previously. Although no manuring had been done for five or more years immediately before the trees were opened up for tapping, all received regular fertiliser treatments for at least two years after planting. Given a good start under careful supervision the young plantings continued to make reasonably good progress during the subsequent period of neglect. Even the four replantings survived remarkably well but it is to be noted that two of these are on coastal alluvial soil where young replants normally grow well without manuring. The unmanured control plots in several areas were lagging behind in the early years but were rapidly catching up with the manured plots in later years immediately before the manuring programme was resumed after the war. Following reoccupation of the country in 1945 the heavy undergrowth was cleared and this in itself had a marked stimulating effect on growth and general condition of the trees. The post-war manuring programme started shortly afterwards when the trees in all areas under consideration were in a healthy condition and showed none of the symptoms usually associated with lack of vigour. The important point is that there was no clear visual evidence to indicate an urgent need for manuring.

Judged on results presented it would appear that the most effective treatment for mature rubber on most inland soil types is one that provides for applications of fertiliser mixtures supplying nitrogen, phosphorus and potassium. The question of supplying magnesium or other plant nutrient elements is not considered in this report but it is fully realised that there will be special cases where additions of nutrient elements other than N, P and K will be required. Responses observed in the trials described are due mainly to nitrogen in the presence of potassium and to the phosphate fertiliser. We find that the average response to nitrogen alone, in terms of both growth and yield of rubber is very small whereas the response to nitrogen applied in the presence of potassium increases steadily, at least up to about the sixth year after the commencement of the manuring programme when the average increase in yield due to this treatment is 5.6 per cent and the average increase in girth increment is 16.3 per cent. The magnitude of the effect in different trials varies over a fairly wide range but this is to be expected in a series of trials carried out on widely separated estates in different parts of the country and on different soil types. The variation is dependent not only on differences between the fertility status of the soils in different sites but also on the degree of accuracy of recording on different estates. By combining and averaging the results of several trials the effect of recording errors is less pronounced. It is perhaps pertinent to mention that in trial No 10 recording of yields and girth increments has been done consistently by one trained worker under rather more careful supervision than is usually possible on the average estate. Furthermore, the yields of all trees in the plots have been recorded twice a month, instead of a limited number of trees once a month as in other trials, so we can accept that yield records from trial No 10 provide a useful standard for comparison in respect to accuracy of recording. It is interesting to note that the trend of effects in this trial corresponds very closely to that shown by the averages of the 17 trials.

We find that phosphate also has a beneficial effect on growth and yield. It has been generally accepted that phosphate fertilisers applied in both immature and mature rubber areas increased rate of growth of trees, and treatment with NP mixtures was generally recommended for young mature rubber. But experimental evidence is now advanced for the first time to confirm that treatment with phosphate after maturity can also be expected to improve yields. It would appear that the effect during the early years is due mainly to application of phosphate during the period of immaturity. An increase in yield per tree during the first few months of tapping due to phosphate applied over a few years immediately before the trees were opened up for tapping has been reported previously (Haines & Crowther 1940). But our experiments provide yield records over a longer period and we find evidence to indicate that the effect of phosphate applied in the pre-tapping period fades out; there is a good indication that the response to phosphate observed in later years is due mainly to the fertiliser applied after maturity. It is to be noted, however, that in our trials there was an interval of about six years before the trees were opened up for tapping when no manuring was done. If fertilisers had been applied regularly during the whole of the immature period, which is now usually regarded as normal practice, it is reasonable to assume that the effect of these early applications of phosphate on yield later would have persisted much longer. But it is reasonable to assume also that this effect would fade out sooner or later and it would seem to be a safe policy to continue the treatment with phosphate after the trees have reached maturity in order to maintain production at a high level in later years.

The need for adding potassium to increase the effect of nitrogen applied to rubber areas has not been reported previously. Current practice locally in manuring of the older rubber areas has been based largely on results discussed in an earlier published

report (Haines & Guest 1936) in which it is concluded that responses to nk and npk treatments were only slightly higher than the response to nitrogen alone and that the extra cost of adding the mineral nutrients was not justified. But when comparing the present results with those discussed in earlier published reports on manuring of mature rubber there are important differences to bear in mind. The results discussed by Mr W. B. Haines and Mr E. R. Guest for instance were obtained from a number of experiments most of which were in areas of backward rubber and in several the trees had been tapped for a number of years. Evidently deterioration had set in before fertiliser treatments were applied whereas the trees in the present trials were in full vigour and newly opened up for tapping. It is pertinent to point out also that the level of application of nitrogen in the experiments described in this report is much lower than in those discussed previously and the interdependence of N and K may have shown up more clearly in the 17 trials than in earlier trials because of this difference in the level of application of nitrogen. It is possible too that, because rate of rubber production in the more recent trials, planted with more modern, high yielding material, was much higher than in the older areas described in previously published reports, the drain on potassium as a constituent of latex may have been appreciably greater. The NK interaction is observed more clearly when measured in terms of yields, although it appears that a similar effect on girth increments may be developing.

The results which have been discussed in the earlier sections of this report cover a period of only about six years following the first application of fertilisers in a programme providing for three biennial applications. In most of the 17 trials the third application was given in the final year of recording of data discussed at present. Clearly therefore, the full effects of this manuring programme have not yet been determined and the percentage effects noted should not be regarded as the likely average total response to manuring. Yield records examined to date are a measure of the crop produced by tapping virgin bark, and the first cycle of tapping on virgin bark is not completed. It is expected that the response to fertiliser treatment, in terms of yield, will at least be maintained for a longer period and may possibly increase, especially when the time comes for tapping renewed bark. In the period which we have covered, the effect of phosphate on yield is small, amounting to only about 2 per cent per annum. It is noted however that the effect on girth increments increased steadily, averaging 12 per cent in the sixth year of recording. Similarly, we find that the average response to nitrogen in the presence of potassium, in terms of both yield and growth, increased steadily from the first to the final year of recording. Since fertiliser treatment improves rate of girthing it may be assumed that bark renewal is also improved. All things considered, it is evident that effects are developing and it is reasonable to assume that still larger responses to the fertiliser treatments can be expected later. Therefore we feel that no useful purpose will be served in attempting, at this stage, to relate cost of treatment with the gain in terms of either increased girth or increased crop.

Although the observations noted above, indicating that mature rubber trees in tapping respond to treatment with nitrogen in the presence of potassium and also to treatment with phosphate, are based on analysis of combined results from the 17 trials, these observations apply strictly only to rubber areas on inland soil types. When we compare the effects of fertilisers in trials on inland soils with those in trials on the heavier, artificially drained coastal alluvial soils, we find that the responses differ in some respects. The most important difference is that in the latter group of trials there has been no noticeable response to phosphate either in terms of growth or yield, whereas on inland soils a beneficial effect due to the phosphate fertiliser is confidently established. On inland soils the effect of nitrogen on yield is marked only in the presence of potassium, but the pattern of effect on yield as shown by the trials on coastal alluvial soils is less clear; there is some indication of a response to nitrogen alone although, as on inland

soils, the effect here also may be enhanced in the presence of potassium. We conclude that for mature rubber areas on inland soil types best results can be expected in the long run from treatment with fertiliser mixtures supplying nitrogen, phosphorus and potassium, whereas for coastal alluvial soils the evidence available now suggests that applications of sulphate of ammonia alone may be regarded as an effective treatment, although we do not rule out the possibility that there might be an advantage from the addition of a potash fertiliser. We must await further information from trials on the alluvial soils before we can make firm recommendations as to the need for potassium.

Regarding the practical application of results of the 17 manuring trials described it is of interest to note in the first place that high yielding rubber trees, even when they show none of the symptoms usually associated with failing vigour, do respond to manuring and that the response, although small at first, is detectable within the first six years after the commencement of the manuring programme. This poses the question whether regular manuring of young high yielding budded and clonal seedling rubber should be done as a matter of routine after the trees have been opened up for tapping. We are not yet in a position to discuss the economic aspect of this question but the results presented in this report provide evidence to suggest that it might be a sound policy which merits consideration. There is certainly no valid reason for supposing that trees which have been manured regularly during the immature period will need no further manuring after reaching maturity. On the contrary there is ample evidence, based on general observations in rubber areas, that deterioration sets in sooner or later and that fertiliser treatment will be required then to prevent rapid decline in yields. It could very well be a better policy to initiate a manuring programme at an early stage in the productive life of the trees as this will at least delay the onset of falling yields and will allow for continued tapping without rest for a longer period. Treatment during the early stages of maturity might be justified too on the grounds that it is easier to maintain good vigour and productivity than to recover that healthy vigour after the trees have deteriorated.

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